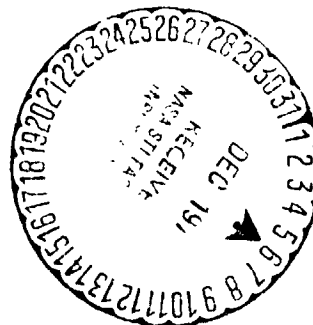NASA CONTRACTOR
REPORT

NASA CR-120500

ZERO-GRAVITY ATMOSPHERIC CLOUD PHYSICS
EXPERIMENT LABORATORY—
ENGINEERING CONCEPTS/DESIGN TRADEOFFS

Volume I: Study Results

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September 1974

Final Report

Prepared for

1 REPORT NO. NASA CR-120500	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4 TITLE AND SUBTITLE ZERO-GRAVITY ATMOSPHERIC CLOUD PHYSICS EXPERIMENT LABORATORY — ENGINEERING CONCEPTS/DESIGN TRADEOFFS Volume I: Study Results*		5. REPORT DATE September 1974
		6 PERFORMING ORGANIZATION CODE
7 AUTHOR(S) R. V. Greco, L. R. Eaton, and H. C. Wilkinson		8. PERFORMING ORGANIZATION REPORT # MDC G5447
9 PERFORMING ORGANIZATION NAME AND ADDRESS McDonnell Douglas Astronautics Company-West 5301 Bolsa Avenue Huntington Beach, CA 92647		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO. NAS 8-30272
		13. TYPE OF REPORT & PERIOD COVERED
12 SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 20546		CONTRACTOR Final
		14. SPONSORING AGENCY CODE

15 SUPPLEMENTARY NOTES

16. ABSTRACT

This study summarizes work accomplished from January 1974 to October 1974 for the Zero-Gravity Atmospheric Cloud Physics Laboratory. This project involves the definition and development of an atmospheric cloud physics laboratory and the selection and delineation of a set of candidate experiments that require the unique environment of zero gravity or near zero gravity.

The primary goal of this effort is to define the experiment program and the laboratory concept for a Spacelab payload to perform cloud microphysics research. This multimission laboratory is to be available to the entire scientific community to utilize in furthering the basic understanding of cloud microphysical processes and phenomenom, thereby contributing to improved weather prediction and ultimately to provide beneficial weather control and modification.

* Volume II: Detailed Approaches, is available as CR-120501.

17. KEY WORDS	18. DISTRIBUTION STATEMENT Unclassified-unlimited
19. SECURITY CLASSIF. (of this report) Unclassified	20. SECURITY CLASSIF. (of this page) Unclassified	21. NO. OF PAGES 560	22. PRICE NTIS

FOREWORD

The results reported herein encompass study efforts performed on the "Zero-Gravity Atmospheric Cloud Physics Experiment Laboratory - Engineering Concepts/Requirements/Design Trade-offs Study" conducted for the NASA Marshall Space Flight Center (MSFC) by the McDonnell Douglas Astronautics Company. This report supplements and updates the information provided by the "Zero-Gravity Cloud Physics Laboratory Candidate Experiments Definition and Preliminary Concept Study" and contained in NASA reports CR 128998, CR 129002, and CR 129013.

The primary goal of the above efforts is to define the experiment program and the laboratory concept for a Spacelab payload to perform cloud microphysics research. This multimission laboratory is to be available to the entire scientific community to utilize in furthering the basic understanding of cloud microphysical processes and phenomenom, thereby contributing to improved weather prediction and ultimately to provide beneficial weather control and modification.

The study scope performed by the McDonnell Douglas Astronautics Company, Biotechnology and Space Sciencies Subdivision, involved the following tasks:

Task 1 — Experiment Laboratory Subsystem Requirements
Experiment laboratory subsystem requirements were reviewed, expanded, and finalized in accordance with the technical guidelines. The experiment classes were utilized to establish the engineering design requirements for the cloud chamber's subsystems. The cloud chamber's subsystems and the experiment classes were evaluated to establish the parameter ranges and tolerances for the ancillary subsystems, as well as for data recording, transmission, and storage equipment. Experiment classes were used to determine the laboratory geometry requirements and operational controls.

Task 2 — Experiment Laboratory Subsystem Definition

Tradeoff evaluations were conducted on all the cloud chambers and ancillary subsystems to establish final subsystem definition. Each subsystem was defined to the component level, and subsystem schematics were prepared. Tradeoffs were based on standard engineering criteria (weight, power, volume, development, status, etc.), Spacelab payload requirements, and with regard to keeping development costs and schedule increases at a minimum.

Task 3 — Experiment Laboratory Technology/Development

Component functional requirements and design specifications were developed in sufficient depth to permit evaluation of currently existing component technology. A survey of component status was conducted and a detailed status summary prepared. This status list identified (1) components currently existing that meet laboratory requirements, (2) components that can be readily modified, and (3) technology-deficient components and equipment that will require prototype development. Component development plans were formulated, in conformance with the subsystem definitions, for all technology deficient components. Subsystems contamination specifications must be established for the various experiment hardware configurations. Procedures must be established for meeting the contamination specifications and maintaining the required cleanliness levels throughout the mission.

Task 4 — Subsystems Evaluation

Cloud Chambers
Assessment of selected cloud chamber subsystem concepts requiring technology advancement or design modification was conducted. The effort performed placed primary emphasis on chamber compatibility with envisioned experiment usage on Spacelab. Priority was given to cloud chamber subsystems required for the "high-priority" experiments that have identified technology deficient components. Cloud chamber subsystems were evaluated to provide assurance of both compatibility with the envisioned experiment classes and design adequacy for experimenter-astronaut operation, including safety considerations.

Ancillary Equipment

Selected ancillary subsystems requiring technology advancement or design modification were evaluated. The effort performed placed primary emphasis on subsystem compatibility with envisioned experiment usage on a Spacelab. Ancillary subsystems were evaluated to provide assurance of design adequacy over the required parameter ranges and tolerances, with both manual and automatic operational control. Evaluation of safety factors and maintenance concepts was performed.

Task 5 — Laboratory Definition

The definition of the experiment laboratory was performed to the level required to permit fabrication of a soft mockup. The laboratory definition reflected the results of the program analysis conducted under this scope of work. The laboratory was based on updated Space Shuttle and Spacelab capabilities, and upon criteria in Appendix A and Appendix B in the RFP. Subsystem schematics reflecting the results of program experimentation were prepared and defined equipment to the component level. Interfaces between subsystems and between the cloud physics laboratory and the Spacelab were delineated. Location of subsystems and equipment within the laboratory were specified. Estimates of weight, power, volume, development, fabrication, and operation costs, mission timeline, and development schedule were provided.

Task 6 — Data Management

A preliminary plan for managing data and its processing requirements was accomplished to include a conceptual operational mode for the laboratory based on current Shuttle system concepts. A data management and processing plan was provided that shows the relationship with raw data, filtered data, data handling techniques, etc., and all interfaces as required relative to ultimate delivery of data to the experimenter. Typical flow patterns were developed.

Task 7 — Cost, Schedule, SRT Requirement

The contractor identified and defined (Phase B — C/D) the costs and cost spreads required to design, develop, and fabricate the laboratory equipment, instruments, instrumentation, etc. The contractor identified a development

schedule for the laboratory (Phase B — C/D) and also identified the required areas of supporting research and technology (SRT) required to support the development of the cloud physics laboratory. All priority categories of SRT technology were included as part of the basic laboratory development efforts by the contractor or his subcontractors.

This project is being conducted on behalf of NASA's Office of Applications and Office of Manned Space Flight. The progress of this Space Shuttle/Spacelab payload has been enhanced by the enthusiastic response and support provided by the members of the cloud physics scientific community. This support is based on the recognition of the significant potential that such a payload may provide to the advancement of the basic understanding of cloud microphysical processes and phenomena. Comments on the contents of this report will be welcomed.

INTRODUCTION

Understanding the microphenomena of cloud physics is one prerequisite to accurate prediction and practical modification of the weather. This understanding can be furthered by conducting certain experiments outside the influence of gravity — hence NASA's Cloud Physics Laboratory, scheduled to begin operating with Spacelab aboard the Shuttle in the early 1980's.

Why does one cloud produce a torrent of large, hammering raindrops — a cloudburst — while others precipitate only a fine drizzle? Why does one cloud rapidly develop and separate electrical charges, producing lightning and thunder, while other, outwardly similar clouds do not? Out of a field of thousands of clouds, several hundred of which contain thunderstorms, why does one develop into a tornado?

It has long been recognized that the answers to these and many other questions about atmospheric behavior depend to a substantial degree upon obtaining a better understanding of the microphenomena of cloud physics. For the past 30 years microphysicists, physical chemists, applied physicists, and meteorologists have been deeply involved in concentrated studies aimed at developing such an understanding. Their work — combined with advances in field observation, data gathering, and information processing — has lead to the improved forecasting we enjoy today, as well as to our limited capability to s.imulate or inhibit precipitation. In fact, the National Advisory Committee on Oceans and Atmospheres (NACOA) states in its Second Annual Report to the President and the Congress that ". . . we appear to stand on the threshold of practical weather modification . . . . "

The ability to control the weather can bring enormous benefits to man. It has been estimated that the ability to forecast accurately for only five days in advance would make possible savings of $2-1/2 billion per year in agriculture, $3 billion in management of water resources, $75 million in retail marketing, and $100 million in surface transportation.

These estimates are for the United States alone. Worldwide figures would be many times as great. And if such savings could result from the ability to forecast precisely and reliably for a mere five days ahead, the savings and increased productivity that would arise from the ability to predict the weather for months in advance, and to change it materially in desired localities, would be almost unimaginable.

A great deal of research remains to be done before weather forecasting and control capabilities of such scope can be achieved. NACOA points out that ". . . it is now time to increase the relative effort on smaller-scale meteoro-logical phenomena . . .", while the joint Panel on Weather and Climate Modification of the National Academy of Sciences and the National Research Council has underscored the need for quantitative information at the micro-phenomenal level. Processes such as nucleation, growth of droplets and ice crystals, generation and separation of electrical charges, and "scaveng-ing" (collection of gases and other atmospheric constituents by droplets and crystals) are of fundamental importance. Many aspects of these micro-phenomena are independent of gravity, and adequate observation under lab-oratory conditions demands that gravitational effects be absent.

It is the mission of NASA's Cloud Physics Laboratory (CPL) to make these gravity-free observations practical, productive, and economically feasible. Conceived as a reusable, general-purpose facility for manned research in low earth orbit, the CPL will be available for experiments originating both outside and within the government. With a planned operational life of several years, the laboratory will accommodate a broad range of experi-ments and will be adaptable to the program dynamics and the needs for supplementary experiments that will develop as the investigations progress.

The laboratory will be flown aboard the Space Shuttle (Figure 1) as a "partial" Spacelab payload. (The CPL will use only a portion of the bay space, sub-system support, and mission time available, and thus will be combined with other payloads to make up a Shuttle/Spacelab mission.) The astronaut-experimenter, working in a shirtsleeve environment, will conduct the cloud physics experiments under the direction — via real-time communication,

Figure 1. Space Shuttle Rendering

where necessary — of principal investigators on the ground. First operations will be in the early 1980's.

GRAVITY: THE NEED FOR ITS ABSENCE

The difficulties that gravity creates in cloud physics investigations are related to the physical dimensions of the field in which the phenomena of interest occur in nature, as compared to the size of the observational volume that can be constructed in the laboratory.

A large cloud may be many cubic miles in volume. The constituents within the cloud — nuclei, droplets, crystals, gases, and so on — are free to move for miles in buoyancy or free fall. During these movements, they are constantly forming, dissipating, associating, dissociating, or passing from one state of matter to another. The average lifetime of discrete particles or groups of particles is 20 to 30 minutes. Within this time, exchanges of electricity and heat take place; droplets and crystals grow, freeze, thaw, evaporate, or precipitate; and the redistribution of energy that produces our weather occurs. Particle diameters are extremely small (0.1 micron is common), and differences in temperature and electrical charge, though often minute, are highly critical.

The researcher attempting to study these phenomena in the terrestrial laboratory must work with a pressure-temperature-humidity chamber that encloses only a minuscule fraction of the volume contained in a natural cloud. When with elaborate care he has produced within this chamber the particles that he wishes to study, he has only a few seconds to observe them before they drift to the chamber floor. If he requires a longer time, he must somehow hold his specimen in place against the pull of gravity. Techniques used for this purpose have included capturing individual particles and placing them on surfaces of waxed paper, teflon, copper, or stainless steel; hanging them on thermocouples; suspending them on threads or on fragments of a spider's web; and "clamping" them between the surfaces of two immiscible liquids. All of these methods have been used with some success — and all have been of only limited value because they introduce effects or forces greater in

x

magnitude than those being studied, or because they prevent interactions among atmospheric constituents.

Several approaches have been tried in attempts to avoid gravitational eff for longer periods of time. Drop towers have been used to obtain nea zero-g conditions for up to four seconds, and aircraft flying on low-g parabolic trajectories can permit observations 14 to 20 seconds long. Vertical wind tunnels, by suspending particles in an upward-moving column of air, have permitted the 20- to 30-minute experiment durations required, but only a small range of particle diameters can be observed at one time because particles of different sizes differ in aerodynamic buoyancy — and uniformity of particle size does not occur in nature.

Sounding rockets and automated satellites have been considered for cloud physics research, but neither has been used. Sounding rockets have been neglected because no more than 10 minutes of experiment time could be obtained per flight, and satellites have had no serious advocates because only limited power, volume, weight, and expendable supplies could be put into orbit — at great expense for experiment automation, data management, thermal and attitude control, and launch.

The manned orbital approach, in contrast, entails no significant constraints. Five or more days of experiment time will be available on Shuttle/Spacelab missions. Particles can be floated in the cloud chamber for the natural duration of the processes being observed. Conditions of temperature, pressure, and illumination can be varied as needed, while thermal, electrical, and moisture parameters can be closely controlled and easily altered. Thus particles can be grown, diminished, frozen, thawed, evaporated, and allowed to migrate, collect, combine, and dissociate just as they would do in a natural cloud — all under conditions conducive to microscopic observation, photography, and precision instrumentation.

By providing these capabilities, the Cloud Physics Laboratory will make possible investigations that could not be conducted before — but it will by no means supersede the terrestrial laboratory. As indicated in Figure 2, many
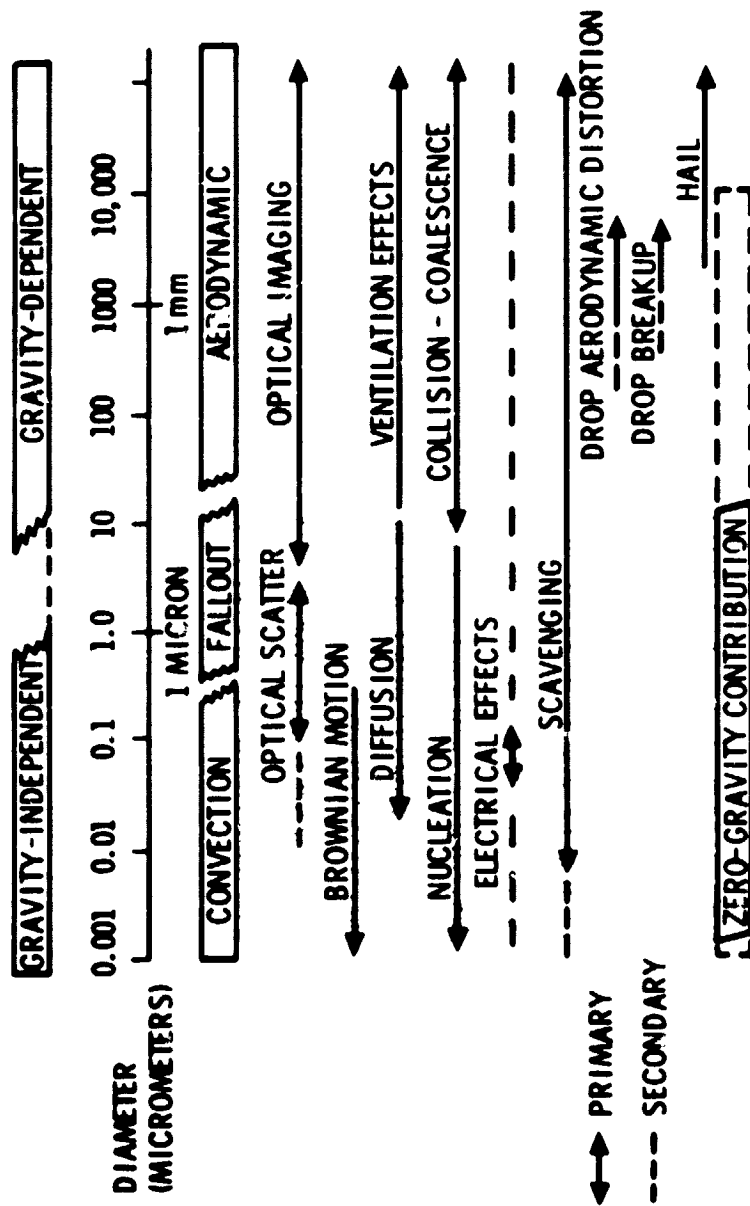
Figure 2. Cloud Physics Regime

cloud microphenomena are gravity-dependent or involve gravity-dependent factors, and much work remains to be done in these areas.

Nor will the CPL go aloft without owing a direct debt to earlier low-g techniques. Drop towers and parabolic aircraft flights have application for development of laboratory elements such as droplet generators and environment controllers.

As a complement to terrestrial laboratories, the CPL may produce technological-fallout benefits for earth-based cloud physics research. At present, terrestrial laboratories tend to be highly specialized for investigation of closely defined microphysical processes. Hence they usually employ one-of-a-kind experiment chambers, instrumentation, and support systems. The CPL, which will use interchangeable chambers supported by standardized systems and a considerable degree of automation, will make available many efficient apparatus concepts and standardized designs that may both ease the tasks of experiment conception and preparation and furnish a basis for direct exchange and comparison of data among researchers.

THE CPL CONCEPT AND HOW IT GREW

The concept of a manned orbital laboratory for zero-g research in cloud physics was first systematically evaluated during the late 1960's as part of an analysis of research and engineering requirements in oceanography and meteorology. This analysis, sponsored by Marshall Space Flight Center, found that the laboratory would be prohibitively expensive if it were self-contained and independently launched. However, it would be economically attractive if it could be attached to and supported by a host vehicle that would provide environmental control, life support, attitude control, data management, communications, and crew quarters for common support of several similar laboratories. Such a host vehicle, the Space Station, was then under study and appeared able to accommodate the CPL with minimum impact on operations, weight, volume, and support systems.

Discussions followed between MSFC and leading cloud physicists in universities, government laboratories, and private research organizations. These

contacts led to the establishment of the Cloud Physics Laboratory as a NASA/
MSFC project sponsored by the Office of Applications.

The project approach was aimed from the outset at responding to the research
needs of the scientific community. Experiment suggestions were solicited
from more than 200 scientists representing 54 organizations, and over 20
visits were made to organizations and laboratories. The experiment sug-
gestions submitted in response, and the corresponding equipment require-
ments, formed the basis for development of experiment classes and pre-
liminary definition of the laboratory design.

Individual scientists participated in organizing the experiment suggestions
into classes and in defining objectives, approaches, experimental methods,
equipment, instrumentation, and data to be obtained for each class. The
results of these efforts, together with the laboratory concept that evolved
in parallel with the classification and survey work, were reviewed by a
group of distinguished cloud physics researchers.

This same approach has been used to refine and adapt the experiment
classes as planning for the national space effort has progressed from the
original Space Station concept to the current Shuttle/Spacelab combination.
The present experiment classes are summarized. The requirements of
these 21 classes can be met by six cloud-chamber types. Two or more
Shuttle/Spacelab flights per year will be needed over a 10-year period.

The laboratory (Figure 3 and Figure 4) will occupy a portion of a Spacelab
module mounted in the Shuttle Orbiter payload bay and will be dependent
upon the host configuration for power, heat rejection, data management,
communications, and astronaut-experimenter accommodations. The CPL
console as currently defined will be 2.70 meters in length, 2.72 meters in
height, and 1.24 meters in maximum depth. Laboratory weight will be
between 998 and 1368 kilograms, and average power demands will range
from 756 to 1155 watts.

The primary criteria underlying laboratory design definition have been value
to the experiment program, low cost, and flexibility to accommodate evolving

WATER
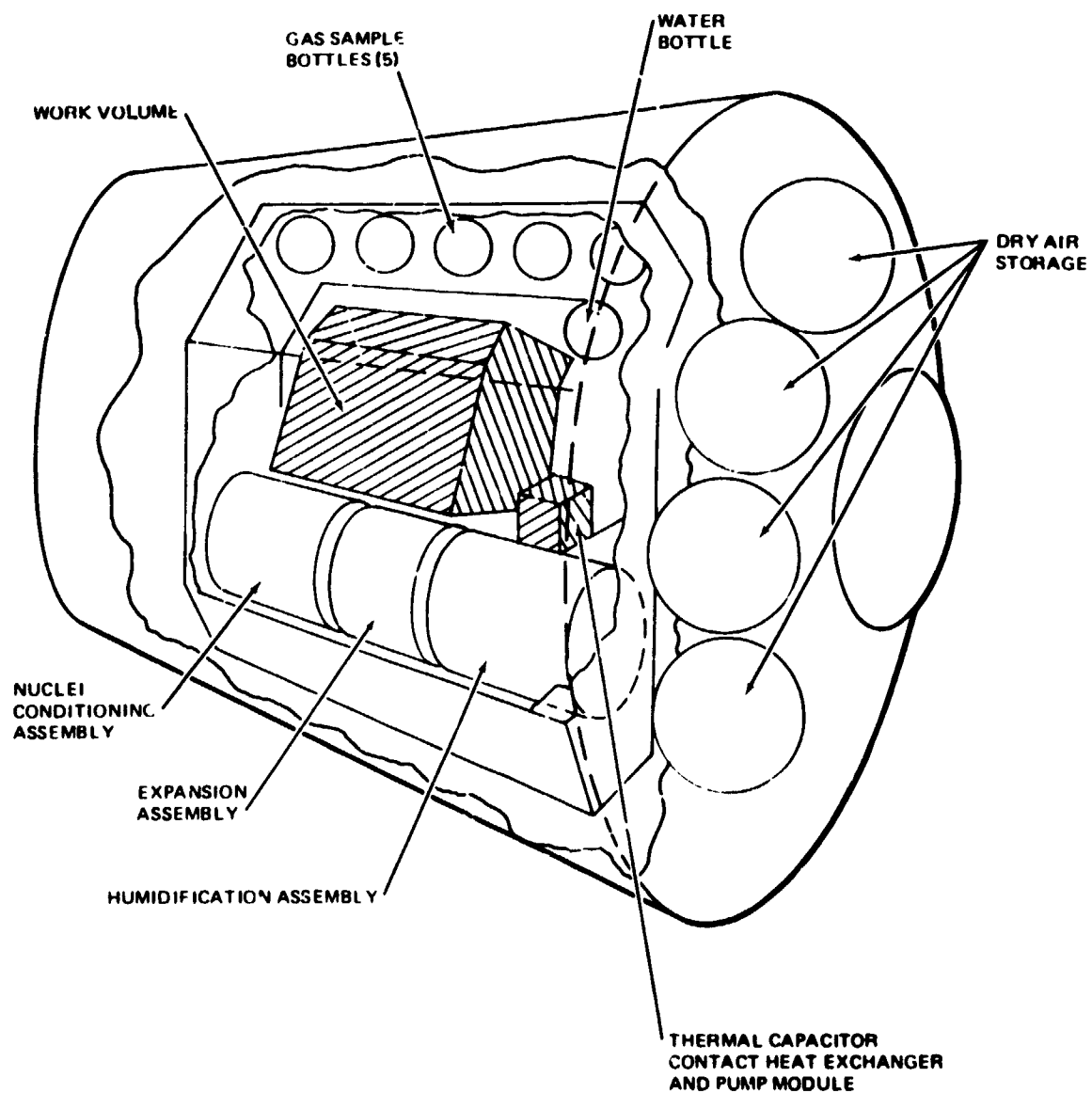BOTTLE

GAS SAMPLE
BOTTLES (5)

WORK VOLUME

DRY AIR
STORAGE

NUCLEI
CONDITIONING
ASSEMBLY

EXPANSION
ASSEMBLY

HUMIDIFICATION ASSEMBLY

THERMAL CAPACITOR
CONTACT HEAT EXCHANGER
AND PUMP MODULE

Figure 3. Cloud Physics Laboratory –Outboard View

STORAGE

TIMING DEVICES

STORAGE

PARTICLE
DETECTORS AND
CHARACTERISTICS

FWD

DATA
DISPLAY
CRT

KEYBOARD

DATA INTERFACE
ELECTRONICS

TOOLS

STORAGE

STORAGE

STORAGE

STORAGE

DISPLAYS AND
STATUS

STORAGE
AND INTERCOM

PARTICLE GENERATOR
GAS SUPPLY AND NUCLEAR
CONDITIONING CONTROLS
CHAMBER CONTROL

INTERCHANGEABLE
CLOUD CHAMBER

VIDEO
MONITOR

FILM STORAGE
OPTICAL STORAGE
FILTER & SLIDE
STORAGE

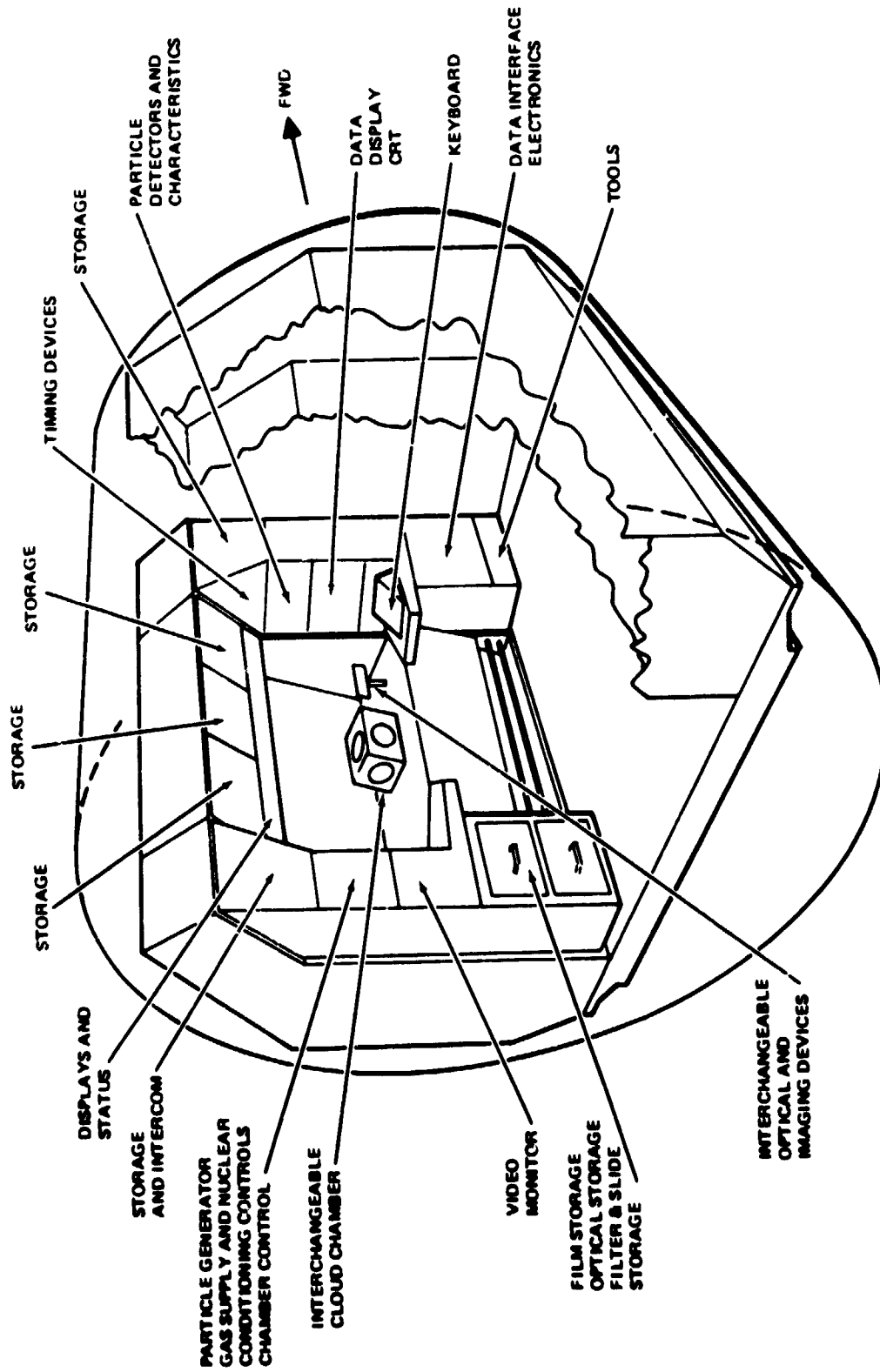INTERCHANGEABLE
OPTICAL AND
IMAGING DEVICES

Figure 4. Cloud Physics Laboratory – Inboard View

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SUMMARY OF EXPERIMENT CLASSES

Experiment Class Number and Title	Primary Chamber*	Alternate Chamber*
1. Condensation Nucleation	CFD	E
2. Ice Nucleation	SDI	E
3. Ice Multiplication	SDI	E
4. Charge Separation	SDI	G
5. Ice-Crystal Growth Habits	SDI	E
6. Scavenging	SDI	G
7. Riming and Aggregation	SDI	G
8. Droplet-Ice Cloud Interactions	SDI	E
9. Homogeneous Nucleation	SDI	E
10. Collision-Induced Freezing	SDI	G
11. Saturation Vapor Pressure	SDI	E
12. Adiabatic Cloud Expansion	E	-
13. Ice Nuclei Memory	E	SDI
14. Terrestrial Expansion Chamber Evaluation	E	-
15. Condensation Nuclei Memory	E	SDL
16. Nuclei Multiplication	G	E
17. Drop Collision Breakup	G	SDI
18. Coalescence Efficiencies	G	SDI
19. Static Diffusion Chamber Evaluation	SDL	-
20. Unventilated Droplet Diffusion Coefficients	SDL	E
21. Earth Simulation	ES	-

*CFD = Continuous-flow diffusion
  E = Expansion
  G = General
 SDI = Static diffusion, ice
 SDL = Static diffusion, liquid
  ES = Earth Simulation

program requirements. Basic subsystems will be designed to remain the same from mission to mission, but features permitting convenient and economical modification or changeover to advanced subsystems will be incorporated to provide for growth and contingencies during the projected operational lifetime. Instrumentation, control, and data recording will feature extensive automation with manual override.

Five standardized cloud chambers (Figure 5) will constitute the primary experiment apparatus. These chambers will be fundamentally identical to those used in terrestrial laboratories but will be distinguished by design features tailored to manned orbital experimentation. Among these features will be heat pipes for thermal control (to conserve power), reduced thermal mass (to reduce weight and increase efficiency in use of experiment time), water reservoirs and flow controls designed for zero gravity, and provisions for meeting the stringent standards of safety and reliability essential to manned space operations. A macroscale experiment, using an earth simulation chamber (ES), has shown a high degree of commonality with microscale experimentation and is presently defined for inclusion in the CPL concept.

THE LABORATORY IN USE

CPL project planning is keyed to making the laboratory available on a schedule compatible with achievement of initial operational capability by the Shuttle and Spacelab. The first two laboratory launches from Kennedy Space Center will be separated by six months. The intervals between missions thereafter will be based on the hours of experimentation required, the time necessary to prepare for each mission, and the flight frequency needed to complete the experiment program within a reasonable period.

Two CPL's are envisioned at this time. Assessment of factors such as flight frequency, preparation time required between flights, design life, life-cycle cost, and flexibility of mission opportunities indicates that this number of units will be adequate to assure attainment of project objectives. Normally, one of the laboratories will be in launch preparation and in orbit while the other is being repaired, refurbished, and modified after completion
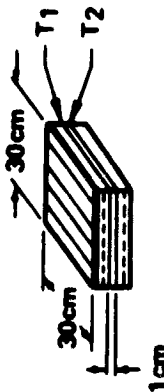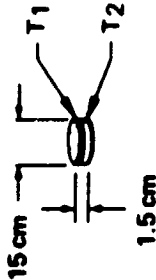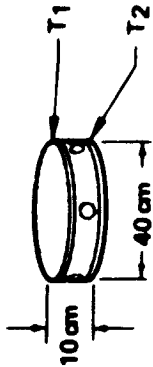
	CONTINUOUS - FLOW DIFFUSION (CFD) T2 < T1 LIQUID SURFACES 0.01 μm < PARTICLE DIAMETER < 10 μm OUTPUT – SIZE DISTRIBUTION CONDENSATION NUCLEATION STUDIES	STATIC DIFFUSION, LIQUID (SDL) T2 < T1 LIQUID SURFACES 0.01 μm < PARTICLE DIAMETER < 10 μm OUTPUT – NUMBERS ONLY CONDENSATION NUCLEATION STUDIES	STATIC DIFFUSION, ICE (SDI) T2 < T1 ICE SURFACES 1 μm < PARTICLE DIAMETER < 1 cm OUTPUT – SIZE, SHAPE ICE CRYSTAL STUDIES
PRESSURE RANGE TOLERANCE	760 TO 700 mm ABS ± 5 mm REL ± 1mm	760 TO 140 mm ABS ± 10 mm REL ± 1mm	760 TO 140 mm ABS ± 10 mm REL ± 1 mm
RELATIVE HUMIDITY TOLERANCE	100% TO 103% ABS ± 0.02% REL ± 0.01%	100% TO 103% ABS ± 1% REL ± 0.5%	80% TO 120% ABS ± 1% REL ± 0.5%
TEMPERATURE TOLERANCE	0°C TO +35°C ABS ± 0.1°C REL ± 0.02°C	0°C TO +35°C ABS ± 0.1°C REL ± 0.02°C	-60°C TO +35°C ABS ± 1°C REL ± 0.1°C
ΔT (T₁ – T₂)	0 TO 10°C	0 TO 10°C	0 TO 60°C
FLOW RATE	0.25 SCFM		

Figure 5. Cloud Chambers (Sheet 1 of 2)

	EXPANSION (E)	GENERAL (G)	EARTH SIMULATION (ES)
	HYDROPHOBIC SURFACES COOLED WALLS 0.01 μm < PARTICLE DIAM. ETER < 100 μm ADIABATIC EXPANSION OUTPUT – NUMBERS, MEAN SIZE CLOUD SIMULATION STUDIES	ELECTRIC FIELDS DROPLETS > 100 μm LARGE-PARTICLE INTERACTIONS	DIFFERENTIALLY HEATED ROTATING SPHERICAL ANNULUS OF FLUID ROTATION RATE – 6 RAD/SEC PLANETARY AND SOLAR CONVECTION STUDIES
PRESSURE RANGE TOLERANCE	760 TO 140 mm ABS ± 2 mm REL ± 0.1 mm	760 TO 140 mm ABS ± 10 mm REL ± 1 mm	AMBIENT N/A
RELATIVE HUMIDITY TOLERANCE	1 TO 100% ABS ± 1% REL ± 0.5%	1 TO 95% ABS ± 1% REL ± 0.5%	N/A — —
TEMPERATURE TOLERANCE	-40°C TO +35°C ABS ± 0.5°C REL ± 0.05°C	-10°C TO +35°C ABS ± 1°C REL ± 0.1°C	+15°C TO +35°C ABS ± 0.1°C REL ± 0.03°C
ΔT ($T_1 - T_2$)	—	—	0 TO 7°C

Figure 5. Cloud Chambers (Sheet 2 of 2)

of a mission. In coping with contingencies, the existence of two units —
combined with designed-in economy and rapidity of repair and refurbishment —
will permit the laboratories to serve as backups for each other and will
impart an ability to take advantage of mission opportunities that may arise
from failure of other payloads to meet their flight schedules. NASA, work-
ing closely with laboratory users, will be responsible for the CPL throughout
the entire mission-preparation cycle, from refurbishment and modification
through provisioning and mating with Spacelab and the Shuttle, to the launch
itself.

It is expected that most laboratory users, particularly during the early por-
tion of the operational phase, will represent the domestic and international
scientific communities. For each mission, a team of principal investigators
will be organized among the users, with selections and assignments being
made by a panel of senior cloud physicists, meteorologists, cloud modelers,
and field experimenters. The principal-investigator teams will formulate
the detailed experiment objectives and timelines, assist in astronaut-
experimenter training and launch preparations, support flight operations,
debrief the astronauts, reduce and evaluate the experiment data, and pre-
pare the experiment reports.

It is also anticipated that interests such as shipping, fisheries, forestry, air
transport, and agriculture may wish to become involved in CPL operations.
The participation of such potential users has so far been indirect (through
contact with the scientific community), but as the project matures, the NASA
procedure for announcement of flight opportunities will be used to alert
special-interest organizations that may desire to support research, par-
ticipate in mission planning, or engage directly in experimentation.

GETTING THERE FROM HERE

The Cloud Physics Laboratory project is now gathering the increased momen-
tum that will culminate in orbital operations. Studies to refine the experi-
ment program and laboratory concept were completed in 1973. Actual flight
experience was gained on the Apollo 16, Apollo 17, and Skylab missions,
during which precursor qualitative experiments and demonstrations of

droplet dynamics substantiated the advantages of zero gravity for cloud physics research and reiterated the value of man as an on-the-spot experimenter and decision-maker. In-depth definition studies now in progress will lead to preliminary design in 1975, followed by development and qualification extending from 1976 to 1980.

Much work remains to be done, but the benefits to be drived will make the journey from 1974 through the operational period well worth the traveling. Long-range prediction and control of the weather could prove to be one of the most important single developments to evolve in the next few decades from space exploration. The Cloud Physics Laboratory is expected to be an important milestones in that evolution.

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Section 1
SUMMARY

This study summarizes work accomplished from January 1974 to October 1974 for the Zero-Gravity Atmospheric Cloud Physics Laboratory. This project involves the definition and development of an atmospheric cloud physics laboratory and the selection and delineation of a set of candidate experiments that require the unique environment of zero gravity or near zero gravity.

General objectives of the Zero-Gravity Atmospheric Cloud Physics Laboratory program are to significantly increase the level of knowledge in atmospheric cloud physics research by placing at the disposal of the terrestrial-bound atmospheric cloud physicist a laboratory that can:

A. Complement and/or supplement the cloud physics research performed in terrestrial laboratories.

B. Incorporate design features which would ensure facility usage over the largest feasible range of research and beneficial application experimentation.

C. Provide a unique laboratory for cloud physics researchers, eliminating the use of mechanical, aerodynamic, electrical, and other techniques which tend to mask data results.

Scientific objectives of the Zero-Gravity Atmospheric Cloud Physics Laboratory project are: to advance the state of the knowledge in atmospheric cloud microphysics, to provide an unique laboratory for cloud physics researchers, and to develop techniques in weather control and modification.

Cloud physics research under zero- or low-gravity conditions offers an opportunity to answer many problems that cannot be solved in earth-based laboratories. By taking advantage of zero gravity to define many of the processes in clouds that are not yet fully understood, man could influence weather by changing, for example, drop distributions and nuclei

concentrations, or by adding pollutant compositions. Under zero gravity, an experimenter can suspend a drop in a chamber and observe its nature for the actual time required for various processes and forces to take effect. The droplet can be frozen and thawed out, and another drop can be propelled into it. Observations can be made of the migration and collection of particulate matter that may be near or around the drop. These characteristics cannot be investigated on earth because of gravity and, in some instances, because of effects of measures taken to offset gravity. Thus, numerous experiments that cannot be done on earth can be performed in this unique environment. The laboratory will be made available to the entire cloud physics community so that a wide variety of important experiments can be performed. Participation of the scientific community was encouraged, supporting research was done at universities, and many valuable suggestions by scientists in industry, Government, and universities were incorporated in the concept.

The results of the study are presented in two volumes:
- Volume 1 — presents the results of the total study effort.
- Volume 2 — presents the detailed approaches identified for each class of the experiment program

The primary contents of Volume I are described in the following. In Section 2, the three phases of the feasibility study (reported in NASA CR 128998, NASA CR 129002, and NASA CR 129013) are reviewed. The first phase of the study accomplished the following:
- A. Developed scientific community support interface.
- B. Solicited experiment definitions.
- C. Selected high-priority experiments.
- D. Determined program feasibility.
- E. Identified a concept for multiple experiment cloud physics laboratory including subsystems and components.

The second phase of the study accomplished the following:
- A. Experiments suggested by the scientific community were defined and classified.

B.   Twenty classes of such experiments that require zero or low
     gravity were identified.
C.   Laboratory requirements were determined, based on the experiment
     class definitions.
D.   A multiple experiment laboratory concept was established to
     accommodate nearly all the experiments.

The final phase of the study accomplished the following:
A.   Experiment program revisions based on scientific community and
     Senior Scientific Board evaluation and critique.
B.   Establishment of three experiment mission timelines.
C.   Formulation of the laboratory concept and major subsystems based
     on experiment class requirements.
D.   Assessment of project technical risk including identification of
     required supporting research and technology (SRT) items.
E.   Formulation of key programmatic aspects of the project.

Section 3 presents the summary of the presently defined experiment program.
The 20 experiment classes for cloud microphysics and the macroscale
experiment class for earth simulator are identified with their objectives.
The primary and alternate cloud chambers for such experiment class are
identified. A summary of the range of experiment timelines is also presented.
The results of the analyses to establish the primary and secondary variables
are presented by experiment class. A priority mission set evaluation and the
total experiment program mission assessment are also presented.

Section 4 describes the rationale, guidelines, constraints, and design fea-
tures used to formulate the laboratory concept. The laboratory description
includes total laboratory characteristics and the subsystems, including
their use and location. Interfaces with the Spacelab, CPL growth, and sci-
entific community participation are included.

Section 5 describes the individual laboratory subsystems, their assemblies
and components and use by experiment class.

Section 6 contains summaries of the major analyses and tradeoffs performed in support of the study. These analyses include the evaluation of phenome- nological factors influencing experiment program conduct. Engineering analyses include the evaluation of contamination/cleanliness, expendable quantities, thermal control, and optics design features.

Section 7 is comprised of four separate sections describing the test philosophy and test plan, preliminary laboratory safety plan, reliability analysis, and maintainability analysis.

Section 8 describes the Supporting Research and Technology (SRT) items identified for the CPL. The SRT assessment methodology and priority ranking are defined.

Section 9 defines the anticipated CPL operations. The project aspects of operations scheduling, laboratory maintenance, refurbishment and reconfig- uration, and principal investigator participation are presented.

Section 10 includes the data management and processing plan. The CPL data processing requirements and their use in establishing data flow to both the principal investigators and to the CPL operations contractor is defined. Identification of Shuttle-Spacelab support and interfaces are included in the plan.

Section 11 defines the major milestones for the CPL project, the laboratory project schedule and the supporting subsystem schedules. The schedule driving factors are presented for all aspects of the project.

The Appendix contains the Work Breakdown Structure (WBS) and Dictionary for the project. This WBS reflects the status of the laboratory and the pro- ject as a result of the efforts conducted in the study.

The primary contents of Volume 2 are described in the following.

Section 2 presents the summary of the presently defined experiment program (as provided in Volume 1 section 3)

Appendixes A through U present the detailed experiment class descriptions for Experiment Classes 1 through 21. The detailed descriptions contain the identification of experiment objectives, justification, applications, approach, limitations, and timelines.

Section 2
PROJECT STATUS AND PROGRESS

The efforts conducted in this study utilized the results of the Zero -Gravity
Cloud Physics Laboratory - Candidate Experiments Definition and Prelimi-
nary Concepts Study (NAS8-28761) as a basis. This study was conducted in
three distinct phases. The results of these efforts are contained in NASA
CR 128998, NASA CR 129002, and NASA CR 129013 for the first, second and
third phases, respectively. The sections identify the status and accomplish-
ments of these study phases.

2.1 FEASIBILITY STUDY — FIRST PHASE (SEPTEMBER 1971 TO JULY 1972)
A primary objective of the September 1971 to July 1972 phase of the feasi-
bility and concept study was to encourage suggestions for experiments from
every institution where cloud physics laboratory work is underway. A
parallel objective was to inform everyone working in the discipline about the
objectives of this program. Agencies involved in weather modification and
field experimentation and cloud-seeding commercial firms were invited to
submit their ideas. Letters were sent to scientists in the field of cloud
physics and weather modification who had articles published in meteorologi-
cal journals from 1968 to 1971. Letters were also sent to those who had pre-
sented papers at the American Meteorological Society cloud physics meetings
including individuals associated with universities, Government laboratories,
and private research organizations. A limited solicitation was made to sci-
entists outside the United States. An explanation of the zero-gravity cloud
physics program was sent to each addressee, including the role of gravity in
limiting terrestrial research, the purpose of the solicitation effort, and the
requirements associated with suggestions — i.e., scientific merit, relevance,
and the need for zero gravity.

In addition to the mail solicitation, visits were made to universities and
Government laboratories where major cloud physics laboratory research

programs were underway, and individual and group conferences were held with many leading researchers in the cloud physics field. An announcement of the study and solicitation effort was also published in the Bulletin of the American Meteorological Society, Volume 52, December 1971.

The response to this solicitation was gratifying (Figure 2-1) and served as the basis for further analysis to prepare and clarify the experiment suggestions for detailed study by the NASA-MDAC Senior Scientific Board. The board independently evaluated the experiment suggestions in terms of scientific merit and relevance and the requirement for zero gravity. Four internationally known scientists in the field of cloud physics and weather modification serve on this board: Drs. C. L. Hosler, L. J. Battan, P. Squires, and H. Weickman.

At its first meeting, held on 3 and 4 February 1972, the Senior Scientific Board selected and classified a set of experiments that met the major program requirements of relevance and scientific merit, as well as the requirement for zero or low gravity. The board agreed that the concept of

INSTITUTIONAL ANALYSIS

	SOLICITATIONS SUBMITTED	REPLIES RECEIVED	SUGGESTED EXPERIMENTS
UNIVERSITIES AND INSTITUTES	27	22	18
GOVERNMENT LABORATORIES	12	8	6
PRIVATE RESEARCH ORGANIZATIONS	8	3	2
FOREIGN METEOROLOGY SERVICES	7	6	5
TOTALS	54	39	31

40 INDIVIDUALS CONTRIBUTED 82 EXPERIMENT SUGGESTIONS

Figure 2-1. Solicitation

accomplishing significant cloud microphysics research in low or zero gravity was clearly feasible.

Engineering problems and requirements associated with the development of a zero-gravity cloud physics laboratory were then identified. This preliminary engineering analysis delineated the various subsystem requirements for the laboratory and indicated potential systems and techniques to meet these subsystem requirements. An additional objective of this phase of the research was to delineate the long-lead-time requirements of the various laboratory subsystems.

Tw) major briefings were prepared during the feasibility study. The first was delivered to personnel of the Marshall Space Flight Center on 23 February 1972 and to staff personnel in the Office of Applications and the Office of Manned Space Flight at NASA Headquarters on 24 February 1972. The second was presented to the Applications Committee of NASA's Space Program Advisory Council on 5 April 1972 at Goddard Space Flight Center, Greenbelt, Maryland.

The briefings established the feasibility of the laboratory and the very important support of the scientific community. There was also general agreement that the program should try to take advantage of flight opportunities prior to Space Shuttle in order to test and develop engineering requirements and concepts and to gather some scientific data. Emphasis was placed on the need for early in-depth definition studies of the candidate experiments.

Several papers and reports were given on such topics as "Zero-Gravity Cloud Physics," "Zero-Gravity Research in Cloud Physics and Weather Modification," and "Summary Description of the Zero-Gravity Cloud Physics Experiment." The substance of the material covered is included in the summary report (NASA CR 128998).

Thus, the significant accomplishments of this study included (1) development of scientific community support, (2) solicitation of experiment definitions, (3) selection of high-priority experiments, (4) determination of program

feasibility, and (5) identification of a concept for the multiexperiment cloud physics laboratory, including subsystems and components of the laboratory, with particular emphasis on those items requiring long-lead-time research and development.

2.2 FEASIBILITY STUDY – SECOND PHASE (JULY 1972 TO APRIL 1973)

The primary objective of the July 1972 to April 1973 phase of the feasibility and concept study was to define the experiment program. A parallel objective was to define the cloud physics laboratory concept. Scientific community support was used in the attainment of the above objectives by formulation of specific experiment class and/or experiment definitions and by participation in definition of specific cloud physics research equipment and instruments. Additionally, precursor experiments for droplet dynamics and NaCl particle breakup were defined.

The cloud physics laboratory experiment program formulation was based on establishment of 20 experiment classes representing different cloud microphysical processes. Expanded definitions of the objectives, the benefits to man and the experiment method for each experiment class were prepared. A discussion section for each class showed, in detail, the significance of the problems being studied, the current difficulties in terrestrial laboratory experiments and the advantages of low-gravity experimentation.

Each experiment class description included, as an example for simplicity and clarity, a definition of a specific experiment. Each class actually includes many experiments that would require variations in method, procedure, and data requirements.

Each experiment class was further evaluated to establish the experiment groups, experiment parameter variations, experiment iterations, and discrete experiment events. As a result, each experiment class was assigned to a specific cloud chamber and mission hours were established for each experiment class.

The experiment program formulation provided the cloud chamber and the preliminary requirements used to formulate the conceptual design of the cloud physics laboratory. The laboratory conceptual design established preliminary characteristics of weight, power, and volume and identification of the subsystems comprising the laboratory.

The Senior Scientific Board was convened for its second meeting in February 1973 to review study progress, giving particular attention to the experiment in-depth definitions and the laboratory conceptual design. The board analyzed each experiment class with regard to scientific priority, chamber requirements, operational difficulty, and application to zero gravity. The board also evaluated the laboratory concept in terms of cloud chamber configurations and laboratory subsystems, including their primary performance ranges and tolerances.

As a result of the Senior Scientific Board meeting, the experiment program was finalized with definition of experiment class and cloud chamber assignment. Priority factor, achievement ability factors, and applicability to low-gravity factors were assessed and categorized. Approval of the laboratory concept was obtained from the board, including approval of subsystem equipment.

During the course of this study phase, two precursor carry-on type experiments were defined for pre-Shuttle flight opportunities. A definition study was conducted for a Droplet Dynamics Experiment. The results of this effort were reported in MDAC report MDC G3787, "Preliminary Definition Study - Droplet Dynamics and Breakup Engineering Demonstration" (July 1972). The major objectives of this experiment are observation of the mechanisms of drop impact, drop stability and drop motion and evaluation of techniques for drop manipulation. Portions of the defined experiment were performed on Apollo 16, Apollo 17, and Skylab II with additional efforts performed by Skylab III and IV.

A definition study was also conducted for an NaCl breakup experiment. The results of this effort were reported in MDAC report MDC G3779, "Preliminary Definition Study - NaCl Particle Breakup Carry-On Experiment for the

Apollo-Soyuz Test Program" (July 1972). The major objectives of this experiment are observation of particle breakup, cloud characteristics and spacecraft motion, and verification of droplet injection and humidification techniques. Subsequent to this study MSFC initiated and sustained a development effort for this experiment.

During this study phase, several long-lead-time technology items were identified and subcontracts were issued to initiate studies in these areas. The chamber subsystems are the primary focal point for the entire laboratory and two chamber subcontracts were issued: (1) a study of potential zero-gravity cloud physics chambers with emphasis on an expansion chamber to the University of Missouri at Rolla (UMR); and (2) a study of potential zero-gravity cloud physics chambers with emphasis on a continuous diffusion chamber to the Desert Research Institute (DRI), University of Nevada at Reno. A study of heat pipes as a means of achieving the important thermal controls necessary for zero-gravity cloud microphysics was completed by the Donald W. Douglas Laboratories at Richland, Washington. McDonnell Douglas Electronics Company (MDEC) of St. Charles, Missouri, performed a small study evaluating holography as an observational tool in zero-gravity cloud physics. Various aspects of thermal control were studied in the MDAC Space Science Atmospheric Physics Laboratory and this laboratory group also studied alternate means of achieving low- or zero-gravity conditions for test and experiment purposes.

Several papers and reports on cloud physics research and applications were given during this study phase. The substance of the material covered is included in Summary Report (NASA CR 129002).

Thus, the significant accomplishments of this study phase included (1) definition of an experiment program consisting of 20 experiment classes; (2) formulation of laboratory requirements based on experiment program definition; and (3) formulation of a laboratory concept accommodating nearly all experiments.

2.3 FEASIBILITY STUDY — THIRD PHASE (APRIL 73 TO SEPTEMBER 1973)
The objectives of the April 1973 to September 1973 phase of the feasibility
and concept study were to refine the experiment program and laboratory con-
cept definition, and to assess key programmatic and operations aspects of
the project.

In this plan experiment class evaluation criteria concerning experiment
priority, applicability, scope, and chamber assignments were formulated.
These criteria and the experiment program descriptions were distributed to
58 scientists who had actively participated during the original experiment
solicitation phase of the program. Seventeen responses were received from
the scientific community. These responses were consolidated and sent to the
Senior Scientific Board (SSB) for their assessment. The resulting inputs
were then used to revise the experiment program descriptions.

The significant evaluations results were:
A. Earth Simulation experiment class definition. This macroscale
   experiment class was found to be compatible with the microscale
   experimentation. An experiment description and equipment
   description was formulated for this class.
B. Primary and secondary cloud chamber approach to experiment
   classes - a revision to the original experiment program approach,
   identifying a single cloud chamber for each experiment class, was
   accomplished. Evaluation of scientific community experiment defi-
   nitions revealed that different aspects of a given experiment class
   could be achieved more easily or with greater accuracy by use of
   more than one cloud chamber. As a consequence of this evolution
   a primary chamber and alternate cloud chambers were identified
   for each experiment class.
C. Unique cloud chamber approach for specific experiments. This pro-
   vision was provided for growth in future missions. Incorporation of
   a unique cloud chamber concept is feasible (within size constraints)
   by usage of the chamber wall/viewport/mounting port features
   common to the identified cloud chambers.

D. Revised Expansion Chamber geometry. This change was identified to facilitate commonality in cloud chamber wall design, and to provide a more direct comparison to terrestial expansion chamber data.

E. Expanded experiment class parameter variations - the parameters to be evaluated were expanded consistent with scientific community interest in evaluating man-produced pollutant influences on microphysical processes.

The laboratory definition efforts, performed in this study, were directed to improvement in definition of the laboratory subsystems. Delineation of the functional and physical characteristics of the subsystem elements was accomplished. The establishment of the rationale for laboratory usage was also formulated. Selection of mission duration, based on the experiment timelines and the identification of the laboratory design life, identified the need for two flight articles.

Evolution of the operations aspects of the project provided the initial definitions for mission control, communications, data management, mission preparation and experiment payload integration.

The involvement of the principal investigation (PI) participation was evaluated: A preliminary procedure for PI selection for experiment missions was formulated and an initial assessment of the degree and extent of his involvement in experiment timeline formulation, astronaut training, simulator operation, flight support and data reduction and evaluation was performed.

The aspects of safety, schedule, cost and supporting research and technology were also refined and updated by efforts conducted during this phase. The evolutions showed that the CPL project could be conducted on a low risk low cost basis, with availability for initial operation in 1980. The CPL furthermore posed no significant potential hazards for the astronaut experimenter.

Section 3
EXPERIMENT PROGRAM SUMMARY

The experiment viability and scientific usefulness of the zero-gravity CPL program relies heavily on the interest and participation of active cloud physics scientists. This participation was reflected by tne involvement of the individuals identified in Table 3-1. These individuals from the scientific community contributed extensively to the reevaluation and refinement of the experiment program as was defined in the NASA Contract Report CR129013 of September 1973. Their input included the delineation of scientific and project pertinent data.

The scientific data included experiment class objective, justification, applications, limitation, and approach as well as the value of the orbital near-zero-gravity experiment opportunity and quantification of pertinent experiment characteristics, parameters, and requirements. Project data included delineation of the groups and parameters within the experiment class, a typical mission timeline, and consumable usage. The format of such experiment descriptions is shown in Figure 3-1 along with significant results of such descriptions.

In general, two independent scientific evaluations were obtained for each experiment class. These inputs were used to establish the CPL Experiment Program and to extract experiment requirements for the CPL. The following subsections identify the Experiment Program and the results of major efforts performed using the Experiment Class descriptions as basic data. Volume II of this report contains an edited version of the scientific community contributions to the Experiment Class Descriptions.

In addition to these major contributors, a survey of project interest and participation was conducted of the general scientific community areas (cloud

Table 3-1
EXPERIMENT PROGRAM CONSULTANTS

Prof. C. Anderson, U. of Wisconsin

Mr. J. Anderson, U. of Nevada

Dr. D. Blanchard, SUNY

Dr. J. Carstens, U. of Missouri

Dr. R. de Pena, Penn State University

Prof. N. Fukuta, U. of Denver

Prof. N. Gokhale, SUNY

Prof. J. Hallett, U. of Nevada

Dr. J. Hart, MIT

Prof. T. Hoffer, U. of Nevada

Dr. K.O.L.F. Jayaweera U. of Alaska

Prof. J. Kassner, U. of Missouri

Dr. U. Katz, CALSPAN

Dr. W. Kocmond, CALSPAN

Dr. G. Langer, NCAR

Dr. J. Lodge, NCAR

Dr. J. Podzimek, U. of Missouri

Dr. J. Spengler, Harvard

Prof. P. Squires, U. of Nevada

Dr. T. Takahashi, U. of Hawaii

Prof. J. Telford, U. of Nevada

Dr. D. White, U. of Missouri

modeling, field experimentation, and laboratory research). A solicitation was sent to 86 scientists. Of the 72 replies received, 63 indicated active interest, 9 of which promised and/or supplied experiment suggestions and descriptions. Responses indicating either a change of scientific area or of lack of interest in the project were received from nine individuals. The survey did prompt requests for additional data and reports and, in general, indicated a high degree of interest and desire to participate in the CPL Project.
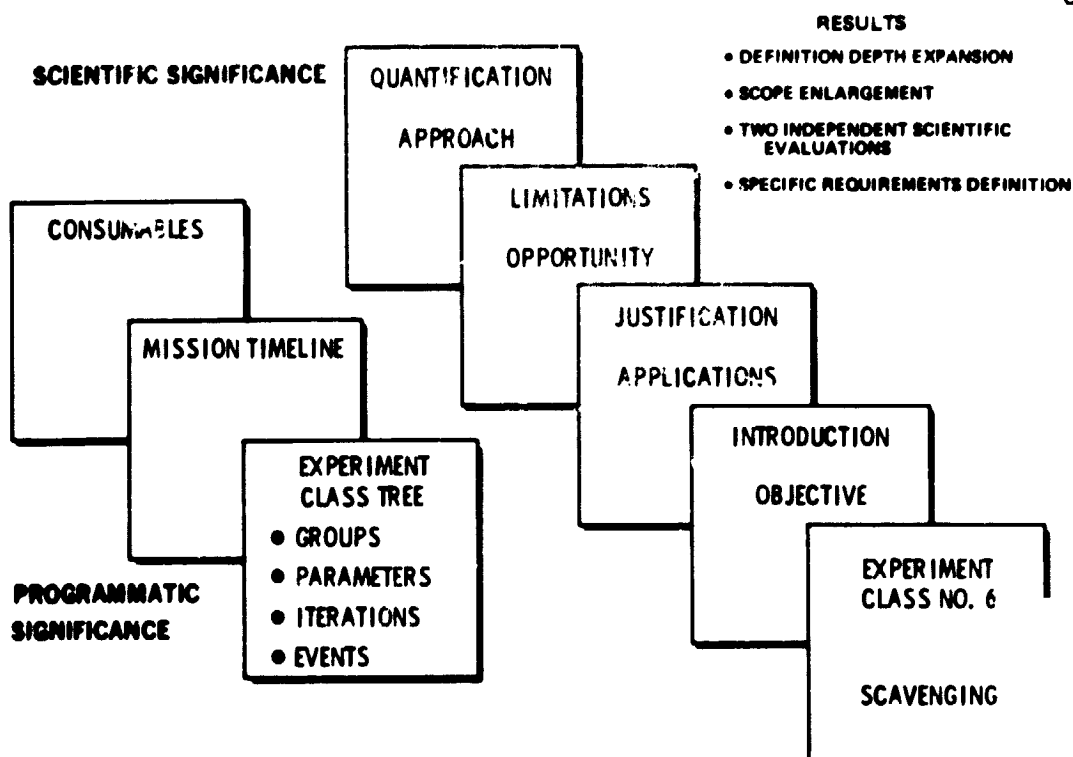
Figure 3-1. Experiment Class Evaluations

3.1 EXPERIMENT PROGRAM

The Cloud Physics Laboratory concept, presented later in this report, was developed to accommodate and satisfy the requirements of the experimentation selected and defined by the scientific community participants. The Experiment Program, as presently formulated, is summarized by Experiment Class Title and Objectives in Table 3-2. This table shows the breadth of experimentation planned to date.

These experiments relate to various phases of precipitation which mainly involve growth by ice and liquid particle collision and adherence through riming, clustering, and coalescence. Collision processes require relative velocities between particles which in turn requires differences in sizes or geometric shapes. These differences are generally due to varying parameters such as condensation nuclei characteristics and humidity distribution.

Most practical weather modification techniques are concerned with the production of a few large ice or water particles in a cloud of many smaller

Table 3-2 (Page 1 of 4)

EXPERIMENT CLASSES AND OBJECTIVES

Experiment ID No.	Experiment Class Title	Objective
1	Condensation Nucleation	Determine the nucleation efficiencies and early growth properties of soluble, insoluble, and hydrophobic nuclei. This class of experiments encompasses a large range of nuclei types, size, distributions, and relative humidities.
2	Ice Nucleation	Determine the relative importance of contact, internal, and sublimation nucleation of ice. Absolute nucleation efficiencies will also be studied as a function of nuclei types and sizes.
3	Ice Multiplication	Determine the conditions under which ice fragments are generated during atmospheric precipitation processes and the extent to which they are generated.
4	Charge Separation (Electrification)	Determine quantitative values for charge transfer occurring during several important atmospheric processes.
5	Ice Crystal Growth Habit	Determine the temperature, pressure, and relative humidity conditions which dictate ice crystal geometry and growth rate under pure diffusion (nonconvective) conditions.
6	Scavenging	Determine the relative and quantitative importance of thermal (thermophoresis), diffusional (diffusiophoresis), and Brownian forces in the collection of submicrometer aerosol particles by cloud droplets and ice crystals.
7	Riming and Aggregation	Determine interaction between a supercooled water droplet and an ice surface during events associated with riming and graupel formation.

Table 3-2 (Page 2 of 4)

EXPERIMENT CLASSES AND OBJECTIVES

Experiment ID No.	Experiment Class Title	Objective
8	Droplet-Ice Cloud Interactions	Determine the modes and extent of the interactions of ice crystals and supercooled water droplets, including the propagation of the ice phase through a supercooled droplet cloud and the diffusional growth of ice crystals within a cloud of supercooled droplets under varying conditions of temperature, pressure, and droplet/crystal concentrations.
9	Homogeneous Nucleation (Ice)	Determine the homogeneous freezing distribution of droplets as a function of time, degree of supercooling, and droplet diameter under conditions of no physical supports.
10	Collision-Induced Freezing	Determine the conditions and frequency of droplet freezing due to collisions of supercooled droplets as a function of droplet size, impact energy, and various ambient conditions of temperature, pressure, and relative humidity. Effects of electric and sonic fields will also be investigated.
11	Supercooled-Water Saturation Vapor Pressure	Determine the saturation vapor pressure of supercooled water.
12	Adiabatic Cloud Expansion Simulation	Duplicate in time and conditions the early portion of the life cycle of a parcel of air involved in an atmospheric precipitation process.
13	Ice Nuclei Memory	Determine the effect of an ice nuclei's history on its ability to initiate (nucleate) the ice phase.

Table 3-2 (Page 3 of 4)

EXPERIMENT CLASSES AND OBJECTIVES

Experiment ID No.	Experiment Class Title	Objective
14	Terrestrial Expansion Chamber Evaluation	Measure condensation and ice nuclei activation efficiencies under operating conditions similar to those utilized in terrestrial laboratories, but without gravity-induced convection.
15	Condensation Nuclei Memory	Determine the effect of a condensation nuclei's history on its ability to initiate (nucleate) the liquid phase.
16	Nuclei Multiplication	Determine the processes and extent of nuclei material breakup.
17	Droplet Collision Breakup	Determine the energy requirements of large droplet-droplet collision-induced breakup as a function of fluid properties, droplet diameters, and external field conditions (sound and electrical).
18	Coalescence Efficiencies	Determine the coalescence efficiencies of small (<50 μm) cloud droplets under varying impact conditions with specific attention toward what happens at the droplet-droplet interface just before and during collision.
19	Static Diffusion Chamber Evaluation	Determine the absolute nucleation efficiencies of standardized nuclei sources utilizing zero fallout conditions.
20	Unventilated Droplet Diffusion Coefficient	Determine the undisturbed diffusion (nonconvective) heat and mass transfer coefficients for growing and evaporating droplets (diameter greater than 10 μm) under various conditions of temperature, pressure, and relative humidity and for various droplet diameters. This class of experiments will include the effects of various atmospheric contaminants on these coefficients.

Table 3-2   (Page 4 of 4)

EXPERIMENT CLASSES AND OBJECTIVES

Experiment ID No.	Experiment Class Title	Objective
21	Earth Simulation	Determine the circulation and instability dynamics of the atmosphere and of the oceans by scaled and simulated experiments.

particles which thus initiates the collision process. These large particles are produced by their enhanced diffusion growth resulting from the lowering of their saturation vapor pressure below that of the ambient vapor pressure. This supersaturation condition can be produced in warm clouds by the addition of giant salt particles which results in a low vapor pressure salt solution. Dry ice (solid CO_2) and various ice nucleating agents (e.g., AgI) are used in supercooled droplet clouds to produce a few frozen droplets with a corresponding lower saturation vapor pressure. In both of these cases, the modified particles grow at an accelerated rate, depending on temperature, humidity and relative numbers of modified to unmodified droplets.

There are four important areas of processes in clouds which must be better understood before productive deliberate modeling and weather prediction and modification can occur. These are nucleation, growth, scavenging, and electrical charge separation and the various classes of experiments can be loosely grouped into these four areas.

A. Nucleation — Nucleation in cloud physics refers to the process of initiating the liquid or ice phase of water. Water vapor (free of ions and particulates) will not form a liquid phase unless a high supersaturation exists and the liquid will not freeze until it is cooled to below -35'C. These two conditions for homogeneous nucleation do not exist under normal atmospheric conditions, but they are of theoretical

interest as a foundation for the understanding of the general hetero-
geneous nucleation processes.

The normal atmosphere contains particles below 1.0-μm diameter that
remain suspended due to their negligible fall velocities. The number of
these particles between 0.01 and 1.0 μm available to serve as condensa-
tion nuclei is sufficient to limit the normal atmospheric supersaturation
to well below 1 percent (relative humidity of 101.00 percent).
Particles larger than 1 μm are generally referred to as "giant
nuclei" and are limited in number due to gravitational fallout
and because they are the first nuclei to become active in water droplet
formation. Giant nuclei are provided artificially for warm cloud
modification.

Ice nuclei are much more limited in numbers than condensation nuclei
because of their special physical requirements. Cloud seeding often
uses the supercooled condition that results from this shortage of ice
nuclei.

Laboratory investigations have shown that once certain particles have
acted as nucleating sites for water or ice, their activation characteris-
tics are changed. This phenomenon is known as an ice and condensation
nuclei memory effect.

Nucleation processes are involved in all forms of weather. At the
present time, most weather modification involves the manipulation of
nuclei (cloud seeding) within a given weather system. Current research
is aimed at determining the role of the various atmospheric nuclei
parameters (number, composition, effectiveness, and sources, includ-
ing pollutants). Further understanding of the role of nuclei will aid
in modification efforts such as: the increase of snow and rain for city
and agricultural use; the decrease of destruction by hurricanes and
hail; and the dissipation of airport and highway fog and smog. Basic
to such modifications is knowledge of the nuclei to use, the appropriate
number to introduce, the proper injection region in the w ather system,
and the optimum injection time during the development cycle.

B. **Growth** — Once nucleation has been initiated, liquid or ice grows by condensation (vapor diffusion) until the particle reaches a few tens of micrometers in size. The quantitative values of the various thermal and vapor accommodation coefficients are very important to this initial diffusional growth phase. Above 20-μm diameter, field observations and theoretical computations indicate that other growth processes in addition to diffusion must be involved in order to explain the growth of particles to millimeter size in reasonable times, where they are able to fall from clouds as precipitation.

Included here are processes such as collision, coalescence (merging of two droplets), aggregation, and riming. These processes require a coexistence of particles (liquid or ice) with a range of sizes. Studies of the growth rates during various phases of growth are an important area of laboratory research and include: diffusional growth under normal atmospheric supersaturations (relative humidities below 101.0 percent), and freezing with possible breakup (splintering) as related to growth processes.

The study of growth processes is important in the "when and where" questions of weather modification while splintering affects the quantities of nucleating materials required.

C. **Scavenging** — Droplets and ice crystals greater than a few micrometers in diameter collect (scavenge) gases, radioactive particles, and other atmospheric constitutents. There is a continuing process of "washing-out" or cleansing of the atmosphere.

Particles below a few micrometers in diameter are collected by several processes, including those associated with Brownian motion, temperature gradients during evaporation (thermophoresis), vapor transport during condensation (diffusiophoresis), gravity-induced collisions (inertial), and electrical forces on charged particles. Normal fallout removes particles greater than 20 μm in diameter. Scavenging is important in connection with ice nucleation efficiencies relative to weather modifications techniques and wash-out efficiencies as related to air pollution problems.

D. __Electrical Charge Separation__ — Cloud physicists are concerned with the processes of obtaining charge separation within natural clouds. Laboratory investigations are concerned with charge transfer processes that occur during collision of ice with liquid or ice. Better understanding of electrical processes has potential in such areas as the reduction of forest fires and property damage due to lightning, and the assessment of the role of electrical phenomena in growth and scavenging processes.

It should be noted that the CPL concept is intended to accommodate not only the experimentation already identified but also be capable of flexibility to accommodate expanded experiment requirements not yet identified. The Experiment Program is, therefore, not yet complete or finalized. Additional project efforts include opportunities for inclusion of experiment suggestion.

3.2 CLOUD CHAMBER SELECTION

The Experiment Classes listed in Table 3-2 provided a working basis for developing experiment requirements. Of prime interest was the designation of the cloud chambers to be used in the Experiment Program.

The individuals identified in Table 3-1 designated their selection of both primary and alternate cloud chambers for each Experiment Class. The primary chamber designation indicated that the major objective of the Experiment Class could be evaluated best in that chamber. The alternate chamber designation indicated that information complementary to the major objective of the Experiment Class could be obtained in that chamber and/or that specific aspects of the Experiment Class necessitated its use. It should be noted that all contributors did not concur on primary and alternate cloud chamber designations and also that more than one alternate cloud chamber exists for many Experiment Classes.

The evaluation of the primary and alternate cloud chambers resulted in the selections shown in Table 3-3. The primary chamber designations are in concert with those identified in the Feasibility Study (NAS 8-27861). The alternate cloud chamber designations reflect reduction to a single alternate cloud chamber for each Experiment Class. The designations, in general,

Table 3-3
PRIMARY AND ALTERNATE CHAMBER SELECTION

Class No.*	Class Title	Primary Chamber	Alternate Chamber
1	Condensation Nucleation	CFD	E
2	Ice Nucleation	SDI	E
3	Ice Multiplication	SDI	E
4	Charge Separation	SDI	G
5	Ice Crystal Growth Habits	SDI	E
6	Scavenging	SDI	G
7	Riming and Aggregation	SDI	G
8	Droplet-Ice Cloud Interactions	SDI	E
9	Homogeneous Nucleation	SDI	E
10	Collision-Induced Freezing	SDI	G
11	Saturation Vapor Pressure	SDI	E
12	Adiabatic Cloud Expansion	E	-
13	Ice Nuclei Memory	E	SDI
14	Terrestrial Expansion Chamber Evaluation	E	-
15	Condensation Nuclei Memory	E	SDL
16	Nuclei Multiplication	G	E
17	Drop Collision Breakup	G	SDI
18	Coalescence Efficiencies	G	SDI
19	Static Diffusion Chamber Evaluation	SDL	-
20	Unventilated Droplet Diffusion Coefficients	SDL	E
21	Earth Simulation	ES	-

*Ordered for data reduction purposes, not by priority.

are based on the consensus of the scientific community recommendations. These recommendations were, however, impacted by considerations of experiment operations, space environment considerations and cloud chamber specification requirements. These considerations generally resulted in alternate cloud chamber selection most compatible with the capability of the cloud chamber (designated based on its primary usage).

The cloud chambers to be used in CPL experimentation are shown in Figure 3-2. The pertinent geometric features, the significant operational features, the use, and the primary requirements are also identified in this figure. The requirements specified are compatible with the Experiment Class usage as primary and alternate cloud chambers.

	CONTINUOUS-FLOW DIFFUSION (CFD)	STATIC DIFFUSION, LIQUID (SDL)	STATIC DIFFUSION, ICE (SDI)
	T2 < T1	T2 < T1	T2 < T1
	LIQUID SURFACES	LIQUID SURFACES	ICE SURFACES
	0.01 μm < PARTICLE DIAMETER < 10 μm	0.01 μm < PARTICLE DIAMETER < 10 μm	1 μm < PARTICLE DIAMETER < 1 cm
	OUTPUT – SIZE DISTRIBUTION CONDENSATION NUCLEATION STUDIES	OUTPUT – NUMBERS ONLY CONDENSATION NUCLEATION STUDIES	OUTPUT – SIZE, SHAPE ICE CRYSTAL STUDIES
PRESSURE RANGE TOLERANCE	760 TO 700 mm ABS ± 5 mm REL ± 1 mm	760 TO 140 mm ABS ± 10 mm REL ± 1 mm	760 TO 140 mm ABS ± 10 mm REL ± 1 mm
RELATIVE HUMIDITY TOLERANCE	100% TO 103% ABS ± 0.02% REL ± 0.01%	100% TO 103% ABS ± 1% REL ± 0.5%	80% TO 120% ABS ± 1% REL ± 0.5%
TEMPERATURE TOLERANCE	0°C TO +35°C ABS ± 0.1°C REL ± 0.02°C	0°C TO +35°C ABS ± 0.1°C REL ± 0.02°C	-60°C TO +35°C ABS ± 1°C REL ± 0.1°C
ΔT (T1 – T2)	0 TO 10°C	0 TO 10°C	0 TO 60°C
FLOW RATE	0.25 SCFM		

Figure 3-2. Cloud Chambers (Sheet 1 of 2)

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	EXPANSION (E)	GENERAL (G)	EARTH SIMULATION (ES)
	HYDROPHOBIC SURFACES COOLED WALLS 0.01 μm < PARTICLE DIAMETER < 100 μm ADIABATIC EXPANSION OUTPUT – NUMBERS, MEAN SIZE CLOUD SIMULATION STUDIES	ELECTRIC FIELDS DROPLETS > 100 μm LARGE-PARTICLE INTERACTIONS	DIFFERENTIALLY HEATED ROTATING SPHERICAL ANNULUS OF FLUID ROTATION RATE – 6 RAD/SEC PLANETARY AND SOLAR CONVECTION STUDIES
PRESSURE RANGE TOLERANCE	760 TO 140 mm ABS ± 2 mm REL ± 0.1 mm	760 TO 140 mm ABS ± 10 mm REL ± 1 mm	AMBIENT N/A
RELATIVE HUMIDITY TOLERANCE	1 TO 100% ABS ± 1% REL ± 0.5%	1 TO 95% ABS ± 1% REL ± 0.5%	N/A — —
TEMPERATURE TOLERANCE	-40°C TO +35°C ABS ± 0.5°C REL ± 0.05°C	-10°C TO +35°C ABS ± 1°C REL ± 0.1°C	+15°C TO +35°C ABS ± 0.1°C REL ± 0.03°C
$\Delta T \; (T_1 - T_2)$	—	—	0 TO 7°C

Figure 3-2. Cloud Chambers (Sheet 2 of 2)

Each of the six chambers that have been identified for use in zero-gravity CPL possess unique characteristics that enhance the investigation of certain aspects of several cloud physics phenomena. On the other hand, a given phenomenological process can be viewed and studied from several approaches utilizing several chambers. These factors were included in the establishment of primary and secondary chamber assignments. The following paragraphs are presented to provide the salient features of each chamber.

Continuous Flow Diffusion Chamber (CFD) - This chamber provides a supersaturated environment for temperatures warmer than the freezing point of water. This chamber provides a rapid throughput of information and provides information on sizes of nuclei and droplets above 0.3 μm in diameter. The chamber characteristics are ideally suited to the study of condensation nucleation and initial diffusional growth of cloud droplets in the 0.3 to 20μm range. Particle concentrations to 10^3 particles per cm^3 at a throughput of 1 cm^3/sec can be accommodated. This chamber is also ideally suited to work in parallel for many of those experiments assigned to the expansion and static diffusion liquid chambers to provide supplementary or comparison data. A fully automated, slightly reconfigured CFD could then operate as a condensation nuclei characterizer.

Static Diffusion Liquid Chamber (SDL) - This chamber provides a controlled supersaturated environment above water freezing temperature and is used to obtain information concerning condensation nuclei numbers that exist in the natural environment. Its use in near zero gravity will be to determine the effects of gravity induced sedimentation and subsequently provide calibration factors which will permit the terrestrial useful range to be extended below the present 0.2 percent supersaturation limit. Additionally, the information gained through the comparison of 1-g and 0-g chambers will permit the design and establishment of a standardized SDL geometry that will then permit a reliable comparison of data from multiple units.

Static Diffusion Ice Chamber (SDI) - This chamber provides a controlled supersaturated environment below water freezing temperature and is used to study various phases of ice and ice/droplet interactions. The types of

experiments involved permit this chamber to have larger dimensions than the CFD and SDL. Ice crystals and/or droplets are injected into the chamber individually or in numbers and subsequent interactions are monitored while the environmental conditions are manipulated. Those experiments which require a saturated or supersaturated environment at below freezing temperatures are appropriate for this chamber. Ice nucleation, ice multiplication, ice crystal growth habits, riming and aggregation are representative experiment classes. Certain aspects of nucleation, growth, scavenging and charge separation are ideally suited to this type of chamber.

Expansion Chamber (E) - The prime feature of this chamber is that it most closely duplicates the natural cloud expansion processes through adiabatic expansion. This expansion influences the relative humidity which exists within the chamber and permits supersaturated and subfreezing conditions. Appropriate cooled chamber walls will permit, in zero gravity, experiment cycles which extend tens of minutes as occurs in clouds. Droplets and/or ice can be injected into the chamber singly or in numbers and the subsequent changes and interactions are monitored as an adiabatic cooling expansion occurs or as a heating compression takes place. The cycle can be repeated as required by the phenomena being studied. The main experiments suited for this chamber are those dealing with clouds of particles. This chamber provides the observation of multiple phenomena taking place simultaneously.

General Chamber (G) - Many of the dynamic experiments do not require supersaturated conditions within the chamber. On the other hand more access and control of the particles within the chamber are required. The General chamber satisfies the requirements of experiments represented by drop collision breakup and coalescence efficiency studies. In addition the controlled uniform, nonsaturated atmosphere is optimum for the study of some aspects of experiments like the saturation vapor pressure over supercooled water, collision induced freezing and riming/aggregation.

Earth Simulation (ES) - This special apparatus provides an enclosure to shield a rotating sphere from ambient thermal and air motions. Although a free-floating object is not required, the low-gravity environment permits the desired radial gravity simulation by use of electrical fields. This equipment is suitable for the study of the circulation of planetary atmospheres and oceans.

3.3 RESEARCH RELATED EQUIPMENT

Evaluation of the detailed Experiment Class descriptions revealed significant commonality in the research tools used throughout the Experiment Program. The research tools were identified in three broad categories.

- Optical Detectors and Imaging Devices
- Droplet Generators
- Particle Detectors and Characterisers

It was further found that these research tools were used in different combinations dependent upon Equipment Class objectives. The CPL concept, therefore, has incorporated these research tools in modular un...s permitting their usage with the degree of flexibility required by such a dynamic area of research.

3.4 MISSION ASSESSMENT

The CPL goal is to be a general-purpose facility capable of accommodating the broadest range of experimentation. The experiments defined to date are envisioned to change or be modified by the results of on-going terrestial research, cloud modeling, and field experimentation efforts. This goal was identified by realization that there exists sufficient microphysical research to be performed that requires or benefits by conduct on a manned orbital platform. The Experiment Class definitions were evaluated to quantify the Experiment Program size and therefore verify the initial assumption.

It must be realized that the quantification of the Experiment Program for the CPL must be extrapolated from the Experiment Class data provided by the scientific community. These definitions, although detailed to sufficient depth, can provide only coarse approximations of the total orbital experiment time required for their accomplishment. The individual experiment

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events vary significantly in the time for their performance, the CPL operations between events are estimated, the "capability level" of the scientist-astronaut has been assumed and the many other aspects influencing experiment efficiency are not sufficiently well known to provide high confidence. The orbital experiment time, and hence mission assessment, is sufficiently accurate to substantiate and justify the general-purpose facility concept for the CPL.

The effective experiment observation time for each experiment class is shown in Figure 3-3. Only those events and operations concerned with microphysical research are included in the effective experiment observation time. The wide variation in duration has resulted from consideration of the primary and alternate cloud chamber usage, the parameters to be evaluated with the experiment class (Figure 3-4), the data gathering instrumentation variations and other pertinent experiment considerations. Both the range and the nominal event duration are shown. For the mission assessment the nominal duration was used as typical for the experiment class.

The experiment classes and the parameters of Figure 3-4 were established based on the experiment class definitions and consideration of CPL capability to provide parameter control. The significant quantity of parameters and their control individually and in combination is provided to satisfy the specified and envisioned desires of the scientific community users. The primary and secondary parameters are shown in the figure. The primary parameters identified are those that terrestrial researchers have identified as having major influence on the microphysical phenomena to be evaluated. The secondary parameters are those whose individual significance to the phenomena being studied is considered minor or must be deferred until the basic phenomena are sufficiently well understood. Combinations of secondary parameters can, however, be of significant importance and capability for their evaluation is therefore provided.

A nominal (or mean) number of variations for each parameter was established and is shown in Figure 3-4. The number of experiment observations was
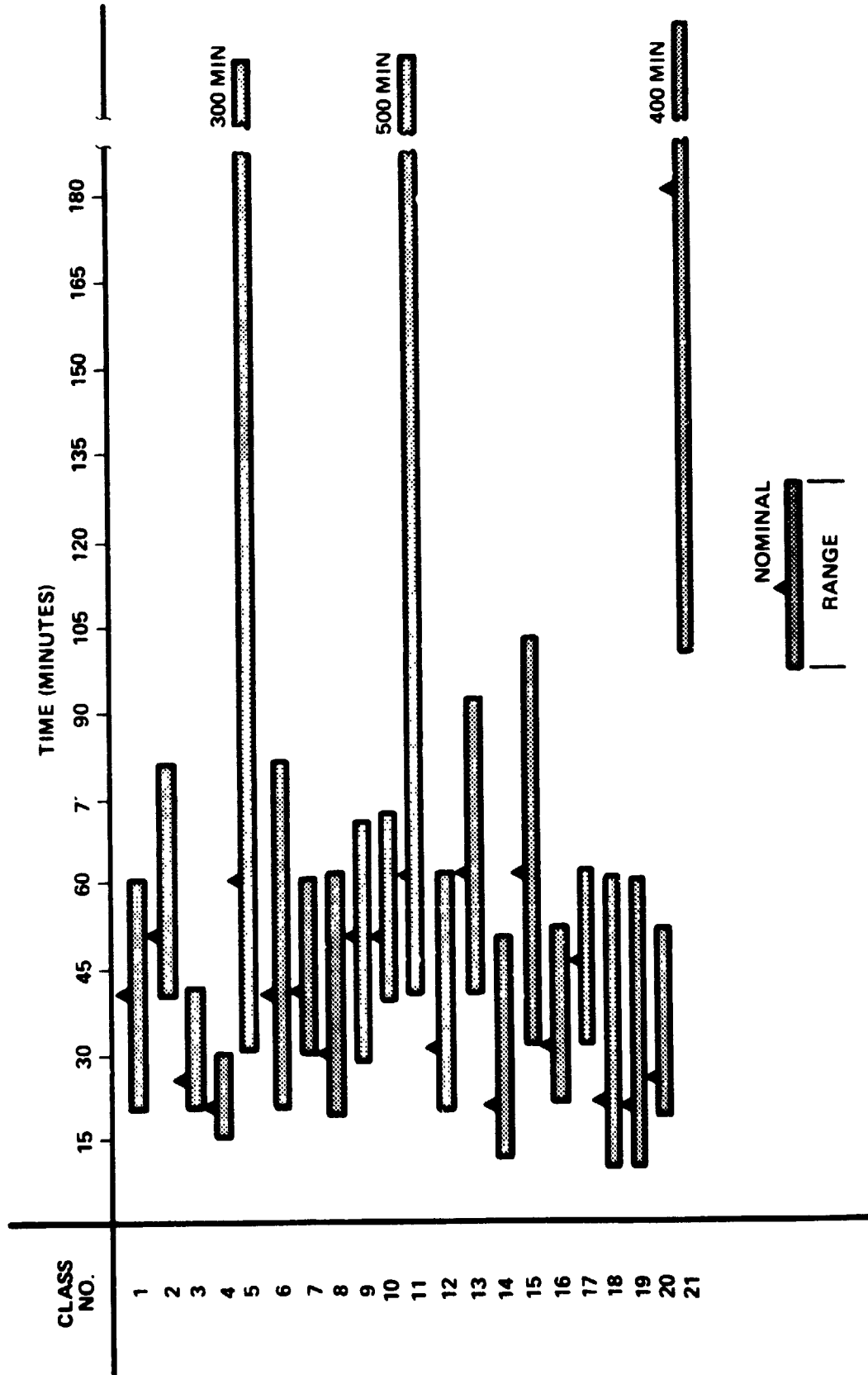
Figure 3-3. Effective Experiment Observation Times

PARAMETERS

Parameters (columns):
SIZE-NUCLEI, SIZE-DROPLET, TYPE, POLLUTANT, PRESSURE, TEMPERATURE, RELATIVE HUMIDITY, CHARGE, RATE OF COOLING, TIME, SOUND, ELECTRIC FIELD, NUCLEAR RADIATION, ADSORPTION, TURBULENCE, VENTILATION, OPTICAL, SHAPE, ORIENTATION, CONCENTRATION, VELOCITY, LIQUID WATER CONTENT, SURFACE TENSION, AEROSOL AGE, HISTORY, ION LEVEL, INITIAL CONDITIONS, KINETIC ENERGY, GASES, SPIN RATE

CLASSES

1. CONDENSATION NUCLEATION
2. ICE NUCLEATION
3. FREEZE SPLINTERING
4. CHARGE SEPARATION
5. ICE CRYSTAL GROWTH HABITS
6. SCAVENGING
7. RIMING AND AGGREGATION
8. DROPLET-ICE CLOUD INTERACTION
9. HOMOGENEOUS NUCLEATION
10. COLLISION-INDUCED FREEZING
11. SATURATION VAPOR PRESSURE
12. ADIABATIC CLOUD EXPANSION
13. ICE NUCLEI MEMORY
14. TERRESTRIAL EXPANSION CHAMBER EVALUATION
15. CONDENSATION NUCLEI MEMORY
16. NUCLEI MULTIPLICATION
17. DROPLET COLLISION BREAKUP
18. COALESCENCE EFFICIENCIES
19. TERRESTRIAL STATIC DIFFUSION CHAMBER EVALUATION
20. UNVENTILATED DROPLET DIFFUSION COEFFICIENTS
21. EARTH SIMULATION

MEAN NUMBER OF VARIATIONS

X = PRIMARY   O = SECONDARY

Figure 3-4. Experiment Parameter Requirements

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established by addition of the parameter variations of the primary parameters only. It is possible to obtain a significantly large quantity of experiment observations by determining the factorial total of both primary and secondary parameters. This would, from the scientific standpoint, provide total "mapping" of the phenomena. The quantity of experiment observations specified for the CPL Experiment Program is therefore conservative (i.e., a much large experiment program can result).

The quantity of experiment missions is shown in Table 3-4. The nominal effective experiment observations times are multiplied by a factor of two to obtain total experiment event time. This 50 percent experiment efficiency factor was considered appropriate based on the feasibility study results and consideration of the operations to be conducted between events. This total experiment event time, the number of parameter variations and the quantity of event iterations were used to determine the number of experiment events and the total number of experiment hours (Table 3-4). By assuming 5 days of experiment operation (during a 7-day mission) and 8 hours of experimentation a day, the number of missions were calculated (40 hours of experimentation per mission).

The significance of the mission assessment identifying 138 missions lies not in the value specified but in the scope of the total research. This scope substantiates the rationale and goal of providing a general purpose facility for the conduct of cloud microphysics research. It should further be noted that the evolving Shuttle/Spacelab projects may revise the number of experiment hours per day and the number of days of on-orbit experimentation (growth to 30-day missions). The general-purpose CPL concept is viable with such change and growth and although the number of missions will vary the >5,000 hours of experimentation can be accommodated.

It should be noted that the Experiment Class 21 (Earth Simulation) was included in the Experiment Program because of its compatibility with the other experiment classes. This macroscale experiment class requires long

Table 3-4

EXPERIMENT PROGRAM MISSION SUMMARY

	Experiment Classes	Parameter Variations	Experiment Hours	Missions	
1	Condensation Nucleation	49	326	8	
2	Ice Nucleation	52	424	11	
3	Ice Multiplication	23	384	10	
4	Charge Separation	32	320	8	
5	Ice Crystal Growth Habits	32	320	8	
6	Scavenging	33	160	4	
7	Riming and Aggregation	24	480	12	
8	Droplet-Ice Cloud Interactions	22	220	6	
9	Homogeneous Nucleation	43	326	8	
10	Collision Induced Freezing	25	226	6	
11	Saturation Vapor Pressure	21	420	11	Total 138
12	Adiabatic Cloud Expansion	29	176	5	
13	Ice Nuclei Memory	33	250	6	
14	Terrestrial Expansion Chamber Evaluation	18	180	5	
15	Condensation Nuclei Memory	25	68	2	
16	Nuclei Multiplication	24	80	2	
17	Drop Collision Breakup	29	132	3	
18	Coalescence Efficiencies	28	760	19	
19	Static Diffusion Chamber Evaluation	25	84	2	
20	Unventilated Droplet Diffusion Coefficients	18	60	2	
21	Earth Simulation	TBD	TBD	TBD	

experiment observation durations and has two primary parameter variations (Figures 3-3 and 3-4). The number of missions required for accomplishment of the objective requires additional evaluation but for planning purposes nine missions are envisioned.

3.4 PRIORITY MISSION RANKING

As presently envisioned the CPL project will use two flight articles and accommodate a launch rate of 4 per year (maximum) equally distributed over the year (one every 3 months). Each flight article is to have a life expectancy of 10 years (20 missions) and capability for extended duration on-orbit experimentation (compatible with Shuttle/Spacelab growth). The total envisioned Experiment Program cannot therefore be accommodated in the first 10 years of flight*.

Priority ranking is therefore necessary and evaluation of the priority mission requirements to total experiment program requirements is necessary.

The mission priority assessment (Table 3-5) was determined using the inputs from the scientific community. Each class was assessed for priority factor, applicability to zero gravity, and achievement ability. A ranking of A (highest), B (nominal), and C (lowest) was provided in each category. The individual scientific community rankings were summarized and factored using the numerical values shown in Table 3-6.

The mission priority ranking developed by the above approach is shown in Table 3-5. The ranking is not deemed to be absolute since only minor numerical total differences exist between many experiment classes. Furthermore, continuing terrestrial efforts will tend to change the priority assessment.

During the 10-year life of the CPL, 40 missions are planned. These missions are allocated (in quantity only, no mission flight order) in

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*Project logic assumes technology advancement and subsystem modular replacement with advanced systems during the 10-year life. It was further assumed that subsequent research would be performed in an advanced CPL.

Table 3-5

EXPERIMENT MISSION PRIORITY RANKING

(First 38 Missions)

Experiment Class Priority	Class No. and Title	Number of Missions	Assessment
1	5 Ice Crystal Growth Habits	3	
2	6 Scavenging	2	
3	18 Coalescence Efficiencies	3	
4	2 Ice Nucleation	3	
5	3 Ice Multiplication	3	
6	1 Condensation Nucleation	3	
7	20 Unventilated Droplet Diffusion Coefficients	2	
8	13 Ice Nuclei Memory	2	
9	4 Charge Separation	2	
10	12 Adiabatic Cloud Expansion	2	• Includes first 17 priority experiment classes
11	16 Nuclei Multiplication	2	
12	19 Static Diffusion Chamber Evaluation	2	• Utilizes all cloud chambers
13	17 Drop Collision Breakup	2	• Requires all laboratory subsystems
14	14 Terrestrial Expansion Chamber Evaluation	3	• Potential reduction in parameter ranges and tolerances
15	10 Collision Induced Freezing	2	
16	7 Riming and Aggregation	2	
17	8 Droplet-Ice Cloud Interactions	0	
18	9 Homogeneous Nucleation	0	
19	11 Saturation Vapor Pressure	0	
20	15 Condensation Nuclei Memory	0	
TBD	21 Earth Simulation	TBD	

Table 3-6

PRIORITY ASSESSMENT NUMERICAL FACTORS

Ranking Value	Priority Factor	Applicability to Zero Gravity	Achievement Ability
A	64	25	11
B	54	18	7
C	43	11	3

Table 3-5. In general the number of missions allocated was established based on the total number of experiment hours for the experiment class. As shown, only 38 flights were allocated, leaving two mission flights for Experiment Class 21, Earth Simulation. Only four experiment classes (8, 9, 11, and 15) are not anticipated for conduct in the first 40 missions.

Experiment Class 21, Earth Simulation, was not prioritized in accordance with the previously described procedure. Since this experiment class involves macroscale phenomena evaluation, comparison and evaluation with microscale phenomena by microscale phenomena scientists was not deemed appropriate. This experiment class is deemed of significant importance and 2 missions of the first 40 missions have been allocated for its performance.

3.6 PRIORITY MISSION SET — TOTAL EXPERIMENT PROGRAM REQUIREMENTS COMPARISON

Evaluation of the priority mission set to total experiment program requirements showed that only minor tolerance and range differences exist. All cloud chambers, droplet generators, particle detectors/characterizers and optical and imaging devices are required. The lack of significant requirements differences combined with the potential for changing priorities, the desire to maintain flexibility for the greatest range of research and the encouragement of total scientific community support resulted in the decision to formulate the CPL concept for the total experiment program.

Section 4
CLOUD PHYSICS LABORATORY CONCEPT

4.1 LABORATORY CONCEPT RATIONALE

The Zero-Gravity Multi-Experiment Cloud Physics Laboratory has been defined based on the concept/philosophy that it serve as a general-purpose facility for the performance of basic research and beneficial application experimentation. A laboratory of this nature is designed so that it will have the capability to efficiently accommodate a broad spectrum of atmospheric cloud microphysical experimentation. Included are those identified in the proposed experiment program and supplementary experiments to be defined as a result of increased knowledge or in response to specific application areas. This approach is particularly necessary in light of the dynamic nature of the research and applications activities related to the project objectives.

The general objective of the laboratory is to complement and supplement the cloud physics research performed in terrestrial laboratories. The major capability of the laboratory is the elimination of gravity-induced motion between particles/droplets and the cloud chambers, thus providing longer observation time to study important forces and processes that occur in nature without using artificial measures to prevent gravity effects (limited observation time). The specific scientific objectives relate to increasing the understanding of microphysical processes, to enable man to improve weather prediction and to ultimately provide weather modification and control.

The cloud physics laboratory is to have an operating life in excess of a decade and therefore attention must be directed to both near- and long-term values. The achievement of project scientific objectives (near-term value - understanding microphysical processes) will advance the scientific knowledge of microphysical processes and will advance man's understanding of his

environment and his impact upon it. The achievement of project application objectives (long-term value - weather prediction, modification, and control) will enable man to constrain, contain, and prevent the uncounted losses of life and property presently attributed to weather phenomena.

The cloud physics laboratory is envisioned as a general purpose facility, available to the entire scientific community, other governmental agencies, qualified industrial organizations, and selected international groups. As such, the cloud physics laboratory would be a significant element for the conduct of weather modification and control related research.

4.2 DESIGN FEATURES

The design features for the cloud physics laboratory were identified to provide the key requirements of value, cost, and flexibility and to satisfy the project guidelines and constraints. These features are as follows:

A. Includes subsystems required for all experiment classes

B. Common subsystems

C. Interchangeable cloud chambers

D. Automated control and manual override

E. Ground refurbishment

F. Capability to accommodate advanced subsystems

G. Capability to accommodate specialized equipment

H. Simplified laboratory to Spacelab interface

I. Maximum utilization of Spacelab resources

J. Operation by one experiment specialist

K. Sensitive equipment storage

L. Safety features to eliminate all credible hazards

Terrestrial laboratories in present concept of research are very specialized and concentrate on specific areas of research. Hence each contains only limited chamber concepts and data-gathering instrumentation. Unlike these ground-based laboratories, the Zero-Gravity Atmospheric Cloud Physics Laboratory will be designed as a general-purpose facility, capable of using several cloud chambers and data-gathering instrumentation.

This flexibility will allow the payload to be used by the entire atmospheric cloud research scientific community. As presently defined, all required cloud chambers, support subsystems, and data-gathering instrumentation can be configured in the laboratory console for specific experiment missions. Multiple reuse, with minor ground refurbishment, will provide an effective operational lifetime of 20 missions. Incorporation of upgraded chambers, instruments, and subsystems can ensure a useful life to more than a decade.

4.3 GUIDELINES AND CONSTRAINTS

4.3.1 Programmatics

4.3.1.1 Definitions

Cloud Physics Laboratory Project

This project includes the definition, design, development, and operations of the atmospheric cloud physics payload and the interface equipment required to interconnect and maintain the payload and the Spacelab. The project also includes ground operations involving experiment mission preparation, experiment specialist training for experiment conduct, experiment mission data evaluation, and laboratory refurbishment and checkout.

Cloud Physics Laboratory

A general-purpose facility for the performance of basic research and beneficial applications experimentation of atmospherics cloud physics. The cloud physics laboratory will be installed within the Spacelab and be transported to and from orbit by the Shuttle. The Cloud Physics Laboratory will provide the scientific community a flexible, low-cost facility capable of accommodating a broad spectrum of cloud physics experiments, with rapid user access and minimum interference with other payloads, the Spacelab, and Shuttle Orbiter activities.

Baseline

The baseline is defined as a fundamental point of reference with regard to project plan, configuration, operations, and experiment program and will serve as a basis for comparison of alternatives.

4.3.1.2 Project Planning

The baseline plan includes two flight units of the Cloud Physics Laboratory, including the associated experiment mission preparation, conduct, data evaluation and documentation in accordance for an assumed 1980 Shuttle flight opportunity in a Spacelab.

The baseline plan includes provisions for payload ground support equipment and experiment missions support hardware and software to assure orderly and timely checkout, flight-readiness verification, and installation into the Spacelab.

4.3.1.3 Environment

The environments experienced by the Cloud Physics Laboratory associated with ground operations and all mission phases of flight operations are contained in the following documents:

A. NASA/JSC - Space Shuttle System Payload Accommodations
   JSC-07700, December 21, 1973*

B. NASA/MSFC - Sortie Lab Users Guide (Interim Issue based on
   US Option)*

C. NASA/MSFC - Sortie Laboratory Design Requirements,
   December 1972. *

The descriptive data itemized in the above documents represent the current Spacelab payload environment and are presented as reference data only as these requirements are subject to change as design requirements of the Shuttle Orbiter and Spacelab evolve from trade studies and design definition maturity.

4.3.2 Laboratory/Concept Justification

4.3.2.1 Concept Justification

The benefits to man of improved weather prediction and the capability to accomplish weather modification and control necessitate the accumulation of

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*These documents will be superseded by updated NASA reports as they become available.

knowledge of basic and fundamental cloud physics phenomena. Evaluation
has shown that terrestrial laboratory research limitations exist and that
these limitations prevent and/or hinder the understanding of phenomeno-
logical processes. A comparison of terrestrial artificial suspension
techniques showed that extraneous forces were introduced and were of such
a magnitude that conflicting data resulted. An evaluation of various
zero-gravity approaches (drop tower, research aircraft maneuver, sounding
and suborbital rockets, unmanned satellites, and manned laboratory) showed
the manned laboratory concept to be superior. Drop tower and research
aircraft maneuvers increased experiment observation time, but not to a
useful degree. Sounding and suborbital rockets provided the required
experiment observation time but constrained experiment equipment quantity.
Satellites required the experiment to provide all necessary support systems
and required total automation of equipment.

The formulation of the experiment program applicable to the orbital near-zero-
gravity environment was based on scientific community suggestions. The
magnitude of the experiment program and equipment defined for its per-
formance further substantiated the manned orbital laboratory concept. The
general-purpose, multiple-experiment mission laboratoy is the only low
cost and cost effective approach for accomplishment of such an experiment
program. Consideration of other factors further substantiates this con-
clusion. The envisioned Shuttle/Spacelab is the only vehicle that can supply
the required experiment mission frequency, the necessary power, thermal
control, data management/communications, and stabilization support
systems and the astronaut-experimenter for conduct of the required
research. The flight frequency is required to maintain terrestrial cloud
physics researcher involvement and permit involvement of many researchers
simultaneously. The Shuttle/Spacelab support systems reduce orbital
laboratory complexity and cost and the astronaut-experimenter provides
the manned decision-making capability for the conduct of dynamic research.

4.3.2.2 Laboratory Description

The Cloud Physics Laboratory, as shown in Figures 4-1, 4-2, and 4-3, is a self-contained unit approximately 2.7 m long, 2.72 m high, and 1.24 m maximum depth with a maximum working volume of $3.64m^3$. The laboratory will weigh between 998 kg and 1,368 kg and will use an average power of 756 to 1,155 watts depending on which experiment class configuration the laboratory is in. The weight, power, and volume by experiment class is shown in Table 4-1. As a partial payload of a Shuttle/Spacelab, the Cloud Physics Laboratory will be dependent on usage of Spacelab resources for

A. Power
B. Heat rejection
C. Scientific crew member operation (astronaut-experimenter)
D. Limited data management and communications

The laboratory (Figure 4-1) contains all subsystems required for the conduct of the defined experiment program. Ancillary subsystems (categorized to denote general support requirement for total experiment program) include:

- Sample Gas Storage, Preparation and Flow Control*
- Console (including power control and distribution)
- Data Management (including displays and controls)

This equipment is installed within the laboratory console shown in Figure 4-1.

The experiment-related subsystems (characterized to denote specialized scientific equipment for specific research areas) include:

- Optical and Imaging Devices
- Experiment Chanbers and Aerosol Conditioning
- Droplet Generators
- Particle Detectors and Characterizers

This equipment is installed in the working volume in the center of the laboratory console or in the console cabinets adjacent to the working volume.

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*Gas storage is provided external to Spacelab on the conical surface of the end dome.

Figure 4-1 Cloud Physics Laboratory — Inboard View

STORAGE

STORAGE

STORAGE

STORAGE

STORAGE

TIMING DEVICES

STORAGE

PARTICLE DETECTORS AND CHARACTERISTICS

FWD

DATA DISPLAY CRT

KEYBOARD

DATA INTERFACE ELECTRONICS

TOOLS

DISPLAYS AND STATUS

STORAGE AND INTERCOM

PARTICLE GENERATOR GAS SUPPLY AND NUCLEAR CONDITIONING CONTROLS CHAMBER CONTROL

INTERCHANGEABLE CLOUD CHAMBER

VIDEO MONITOR

FILM STORAGE OPTICAL STORAGE FILTER & SLIDE STORAGE

INTERCHANGEABLE OPTICAL AND IMAGING DEVICES

4-7

WORK VOLUME

GAS SAMPLE
BOTTLES (5)

WATER
BOTTLE

DRY AIR
STORAGE

NUCLEI
CONDITIONING
ASSEMBLY

EXPANSION
ASSEMBLY

HUMIDIFICATION ASSEMBLY

THERMAL CAPACITOR
CONTACT HEAT EXCHANGER
AND PUMP MODULE

Figure 4-2 Cloud Physics Laboratory — Outboard View
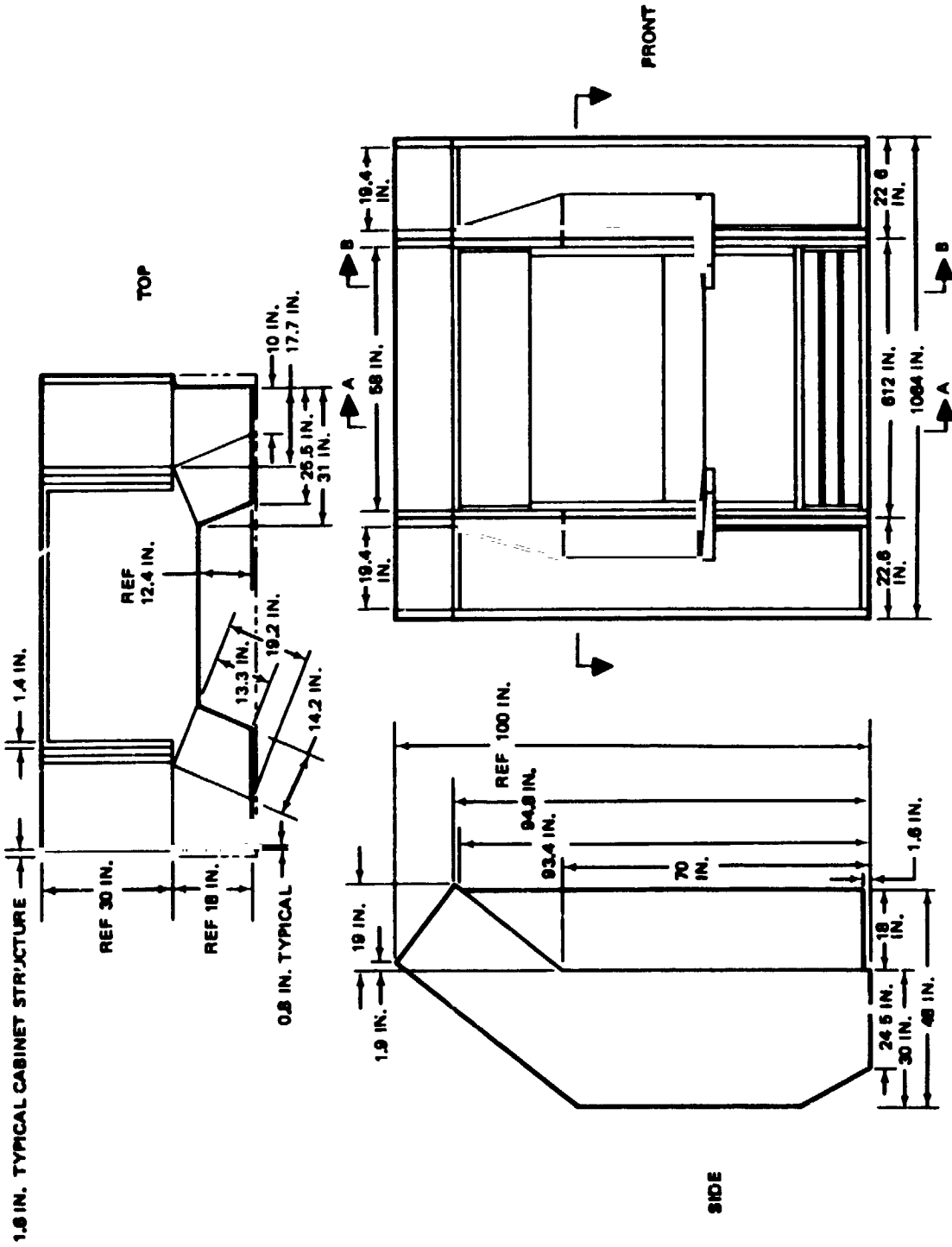
Figure 4-3 Cloud Physics Console Configuration.

Table 4-1

WEIGHT, VOLUME, AND POWER

Experiment Classes	Weight (max) Including Primary Chamber Only (kg)	*Volume Inside Laboratory Excluding Console (m³)	Power Nominal (watts)	Power Average During Experiment Time (watts)
1	1,243	1.620	2,276	963
2	1,280	1.609	2,291	934
3	1,265	1.394	2,416	923
4	1,205	1.416	2,562	961
5	1,274	1.431	1 998	895
6	1,352	1.729	2,788	925
7	1,211	1.434	2,414	978
8	1,291	1.581	2,786	1,014
9	1,156	1.394	1,763	814
10	1,201	1.410	2,197	899
11	1,168	1.398	1,829	777
12	1,363	1.978	3,432	1,155
13	1,279	1.754	2,261	756
14	1,368	1.934	2,879	947
15	1,318	1.809	2,440	876
16	1,364	1 748	2,888	1,000
17	1,204	1.431	2,437	913
18	1,199	1.431	2,437	913
19	1,139	1.115	1,986	765
20	1,256	1.568	2,286	883
21	998	0.878	1,389	756

*Note
1. Volume does not include 0.724-m³ gas storage outside lab.
2. Volume includes only experiment equipment to be installed inside the 3.64-m³ console.

The laboratory flown will be modified for each individual experiment mission. The ancillary subsystems (the major portion of the laboratory equipment) will be used for all missions with specific cloud chamber subsystems. The laboratory, within given limits, can be configured and operated to use available Spacelab resources for a specific mission (volume is fixed - astronaut time, power, heat rejection, and data management support are flexible).

The laboratory subsystems were defined with consideration of ground refurbishment/replacement without major rework. Capability for growth and/or advanced subsystem installation was provided. Sensitive equipment storage is provided in the laboratory as is space for specialized tools required for experiment conduct.

4.3.2.3 Equipment Location

The position of all major components in each of the subsystems are shown in Figures 4-1 and 4-2. The control and display locations and the work area layout for each of the six experiment chamber configurations are given on Figures 4-4 through 4-9 with detailed information given in the following paragraphs.

Thermal Control/Expendables Storage and Control Subsystem

This subsystem will be permanently mounted and fly on all missions.

The thermal control assembly is behind the video monitor on the left side of the console and directly above the humidification chamber. This provides minimum interface plumbing with the Spacelab's thermal control system. The water storage and sample gas storage is located along the back and top of the console and would be accessible from the front through the storage area or the rear when being refurbished. The dry air storage is located outside on the conical section of the Spacelab.

The subsystem status displays are located along the front of the console directly over the working area. The controls are located on the left control panel.
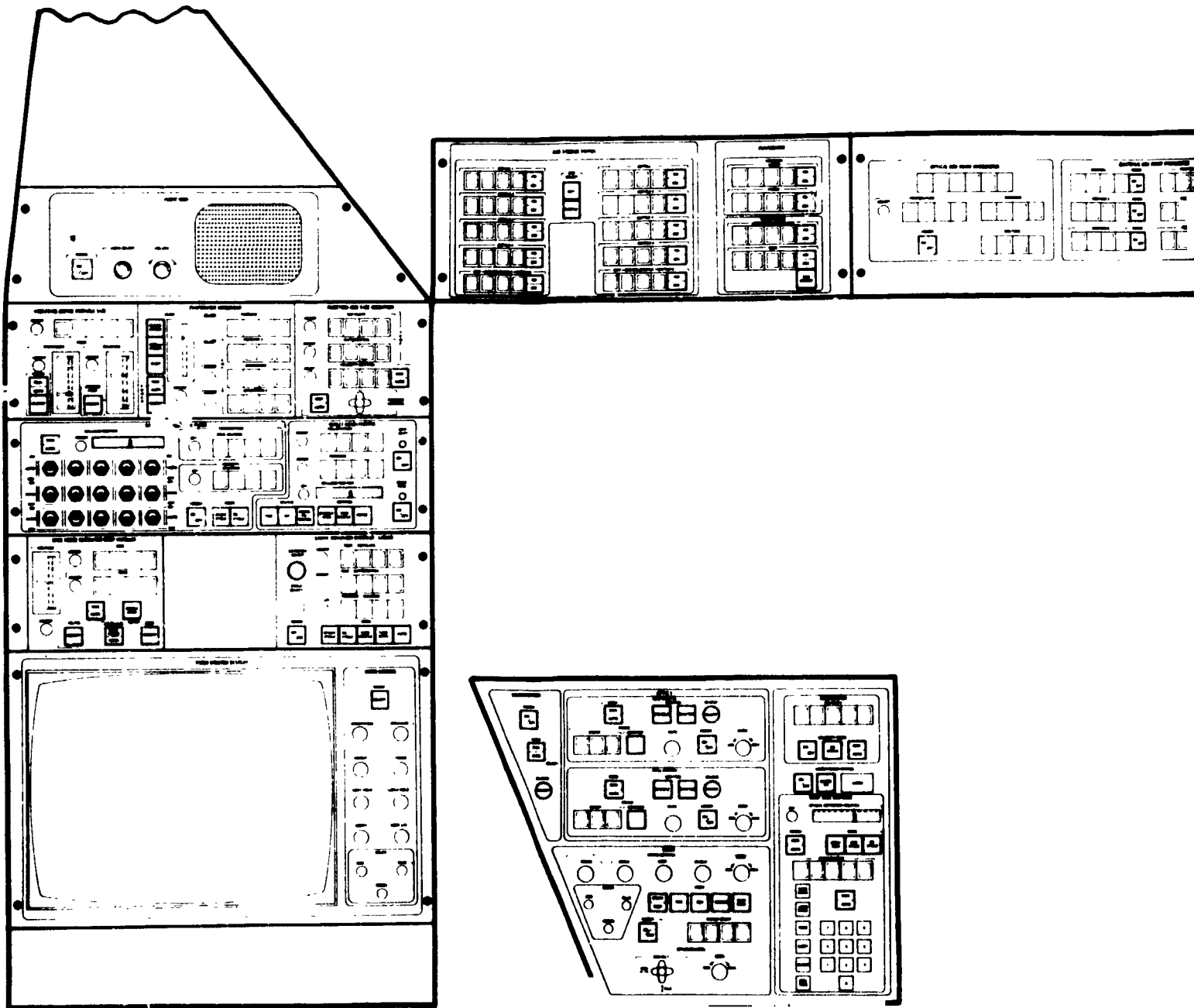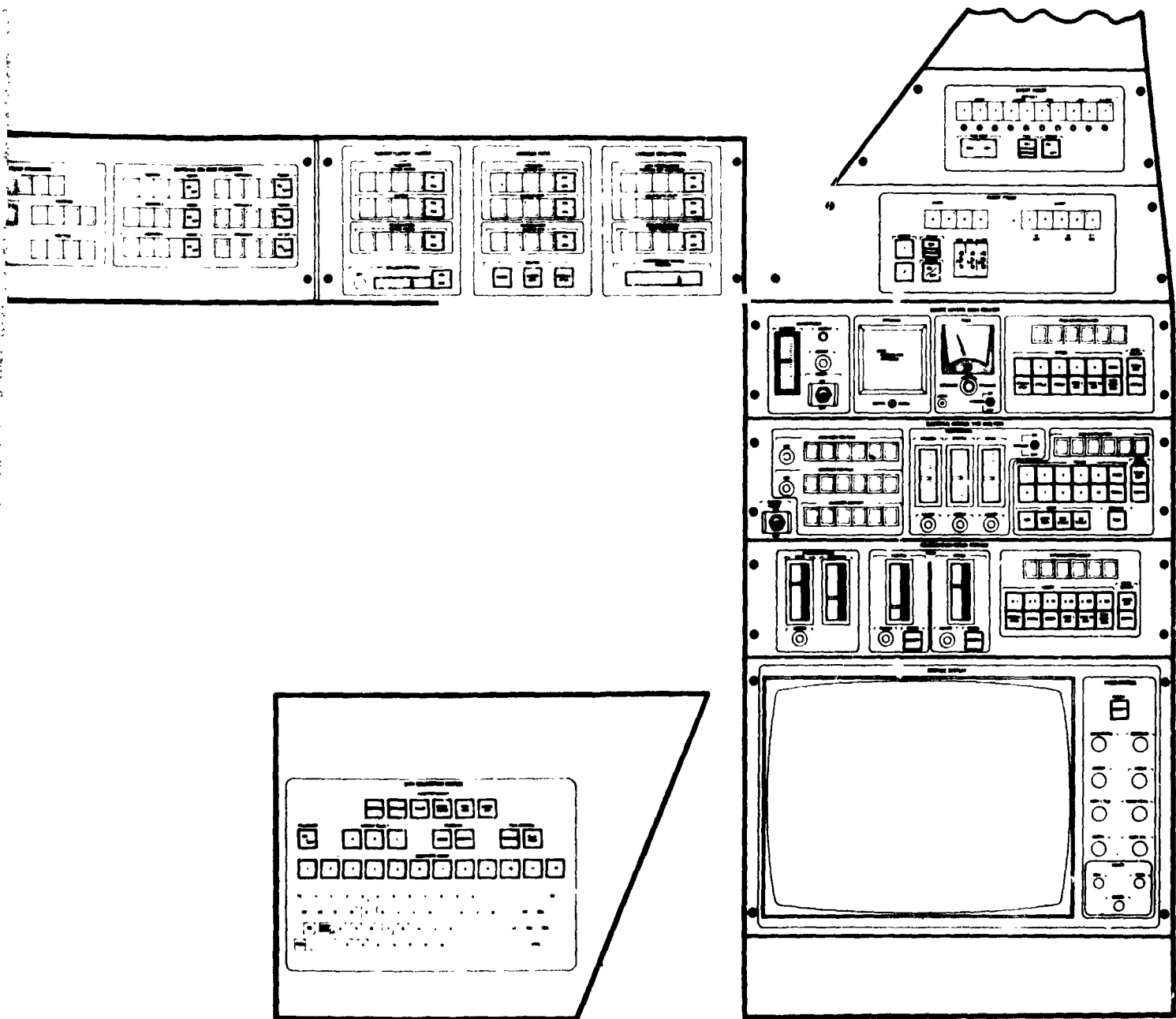
Figure 4-4. Static Diffusion Liquid Chamber Coefficient (Sheet 1 of 2)

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Figure 4-4 (Sheet 2 of 2)

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Figure 4-5. Static Diffusion Ice Chamber (Sheet 1 of 2)

Figure 4   nest 2 of 2)

Figure 4-6. General Chamber Configuration (Sheet 1 of 2)
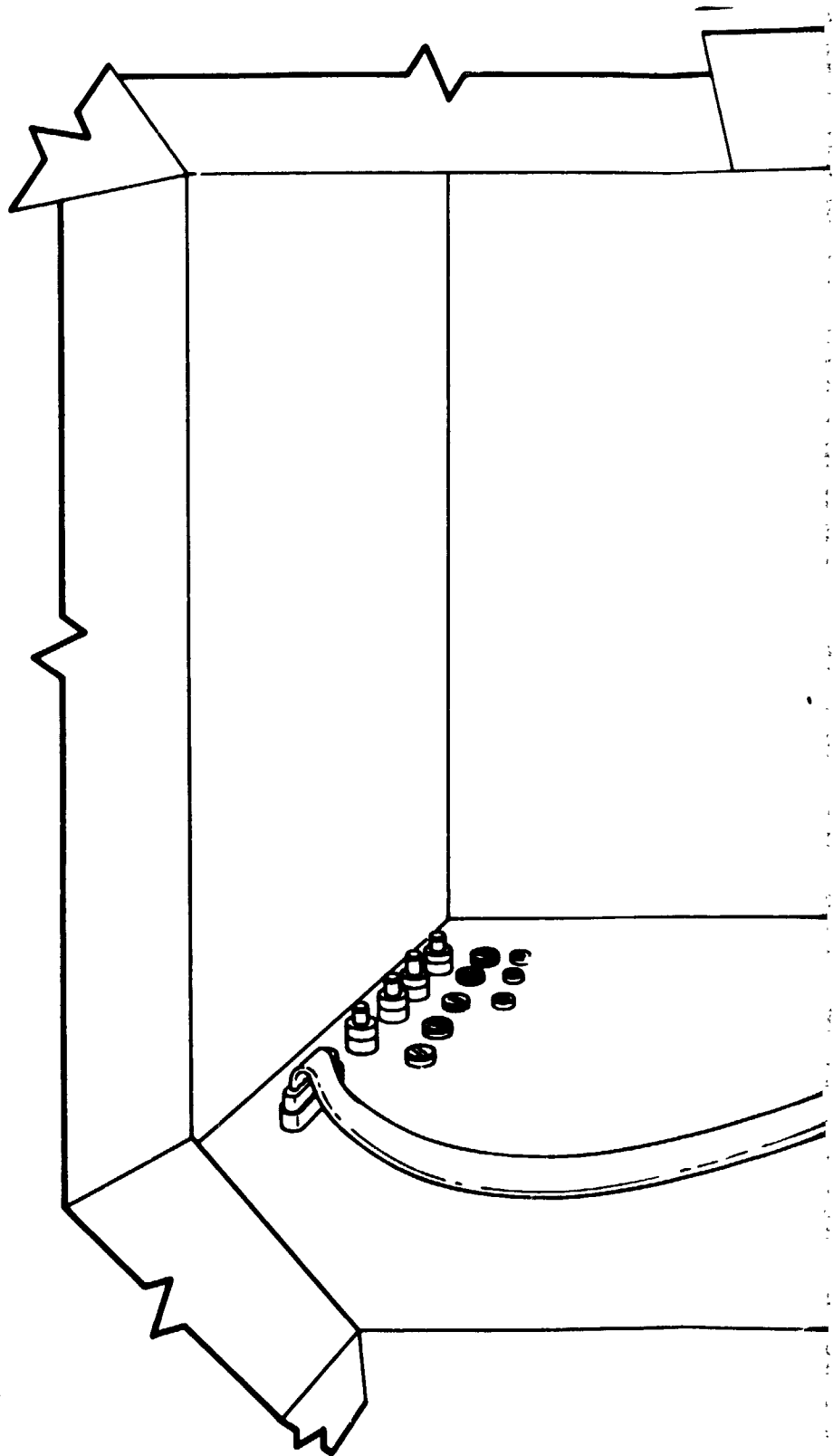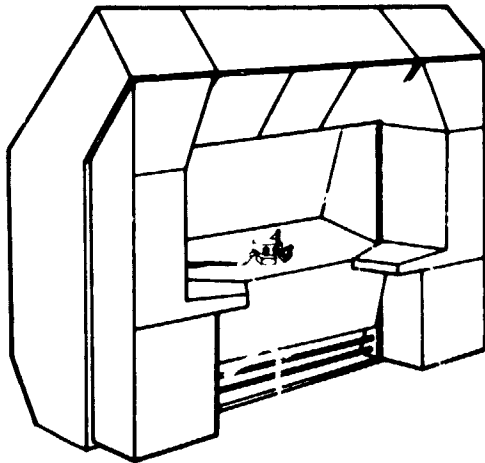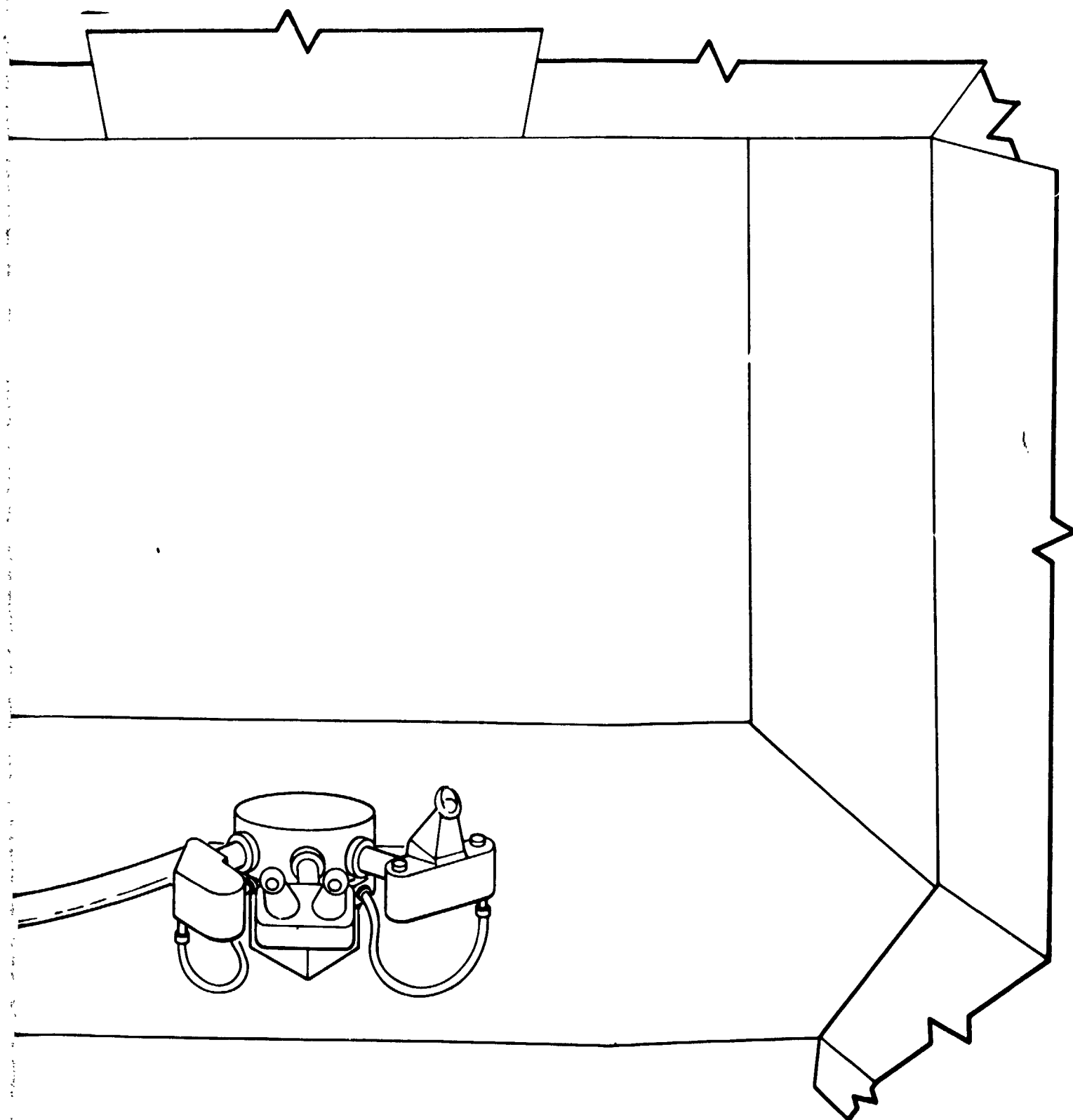
Figure 4-6 (Sheet 2 of 2)
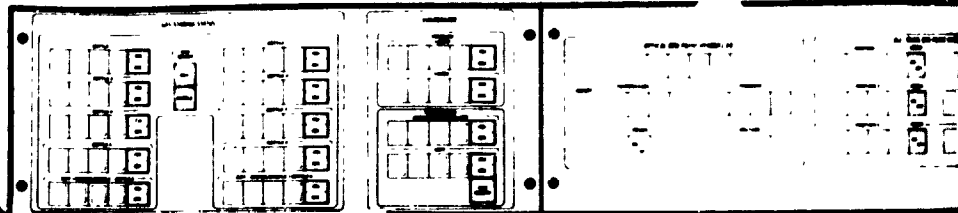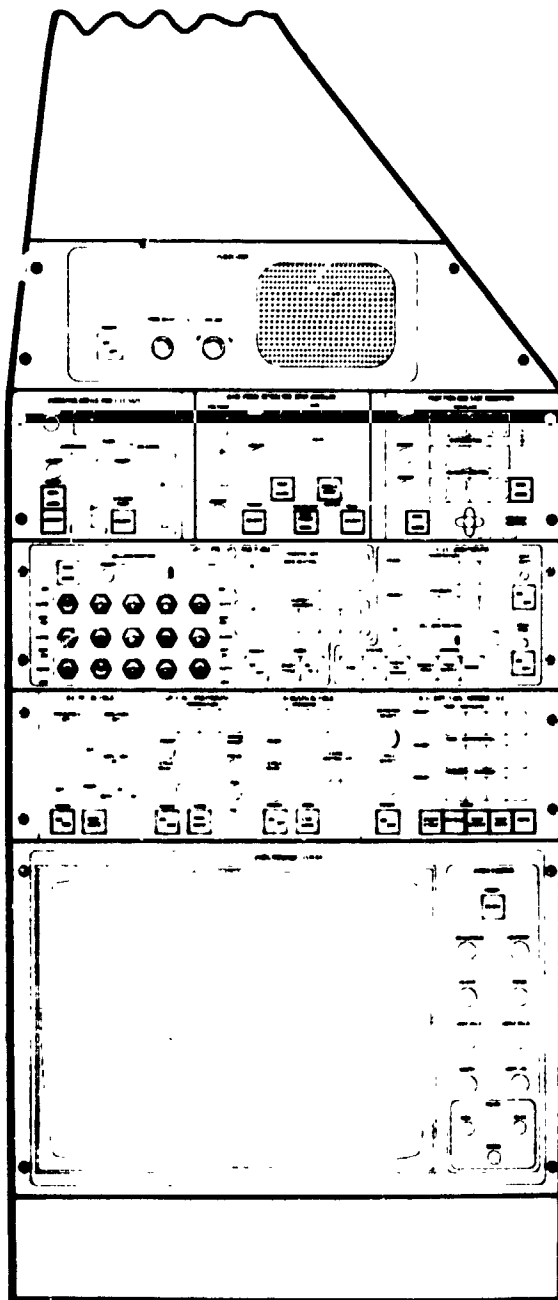
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Figure 4-7. Expansion Chamber (Sheet 1 of 2)
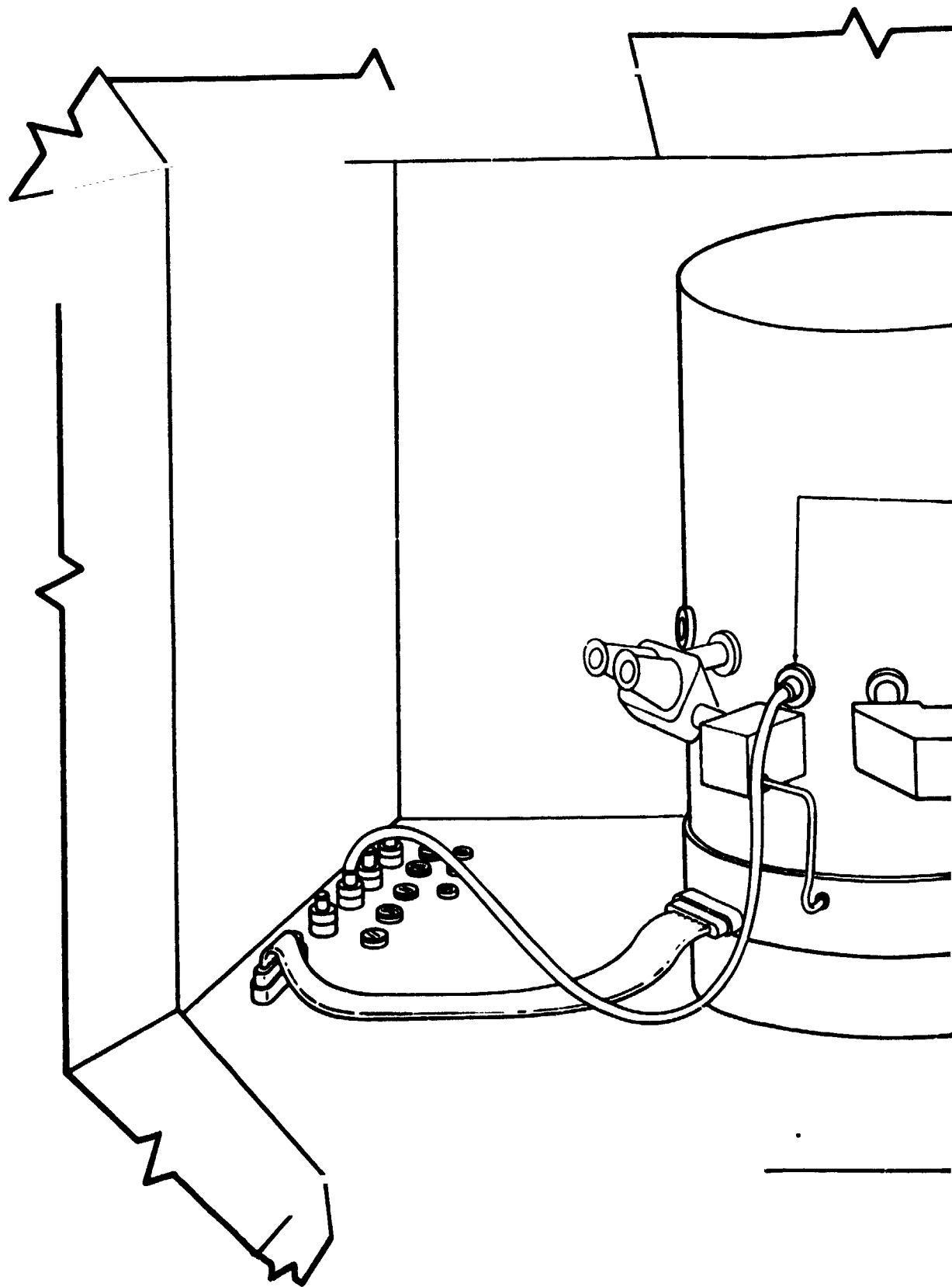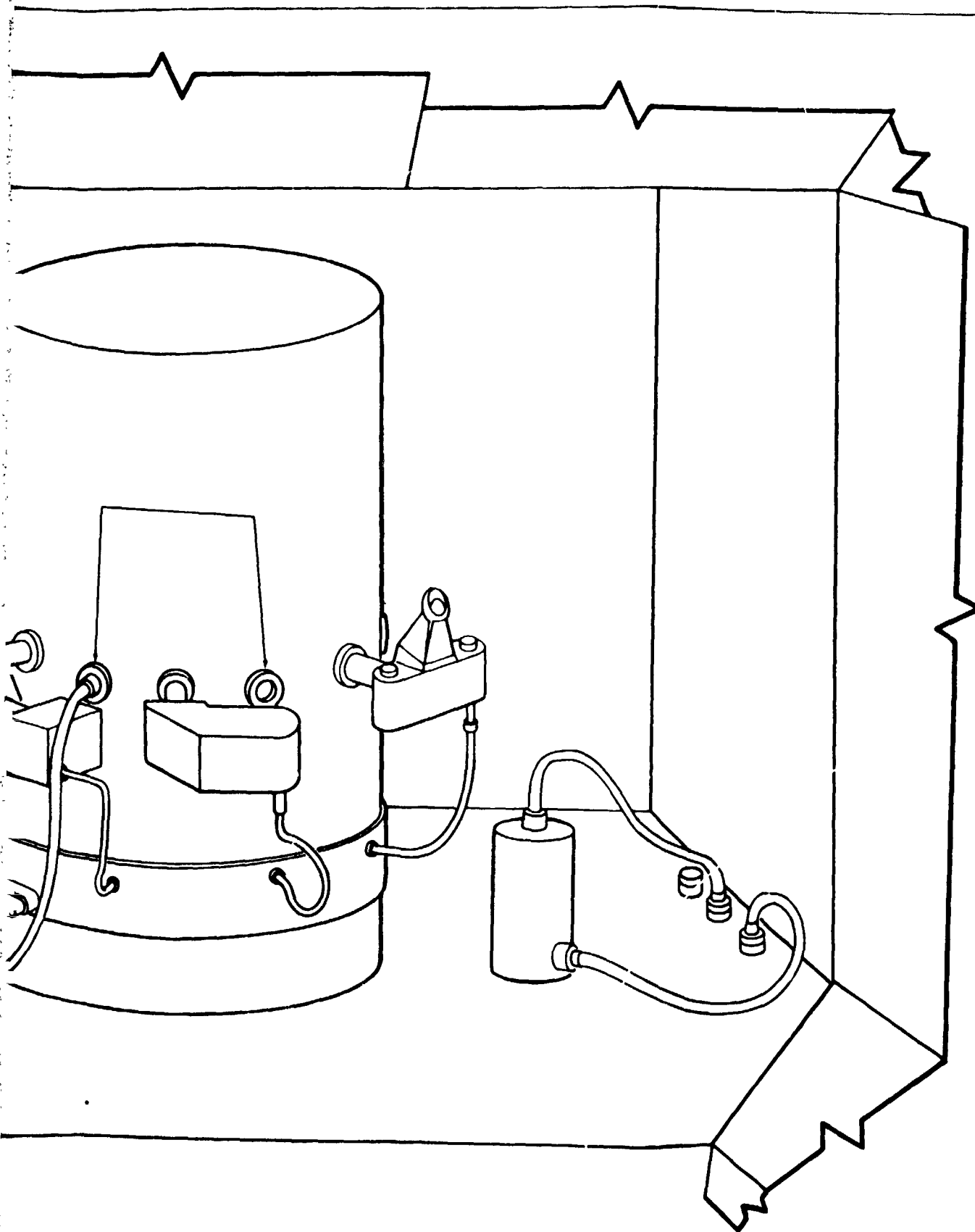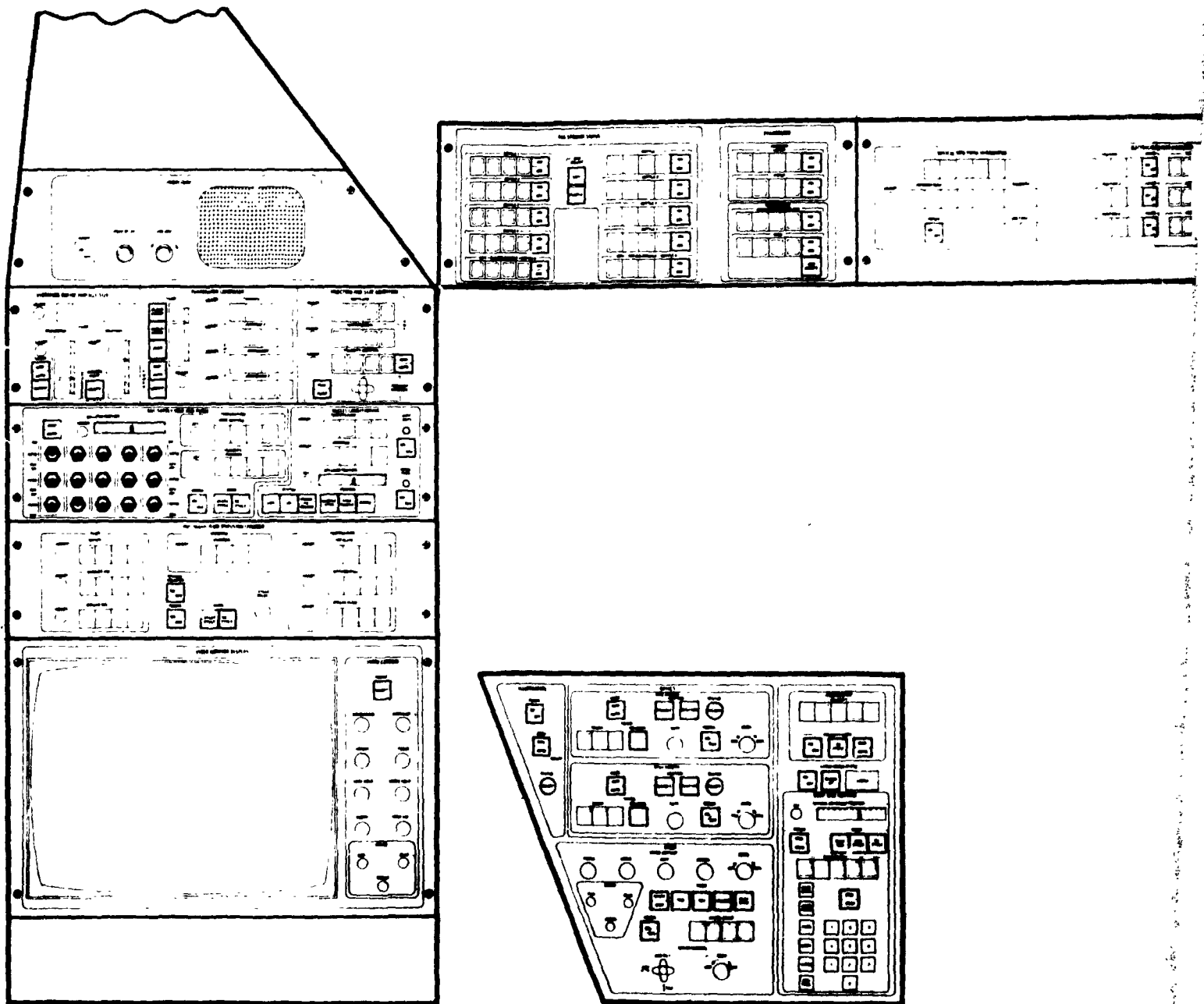
Figure 4-7 (Sheet 2 of 2)
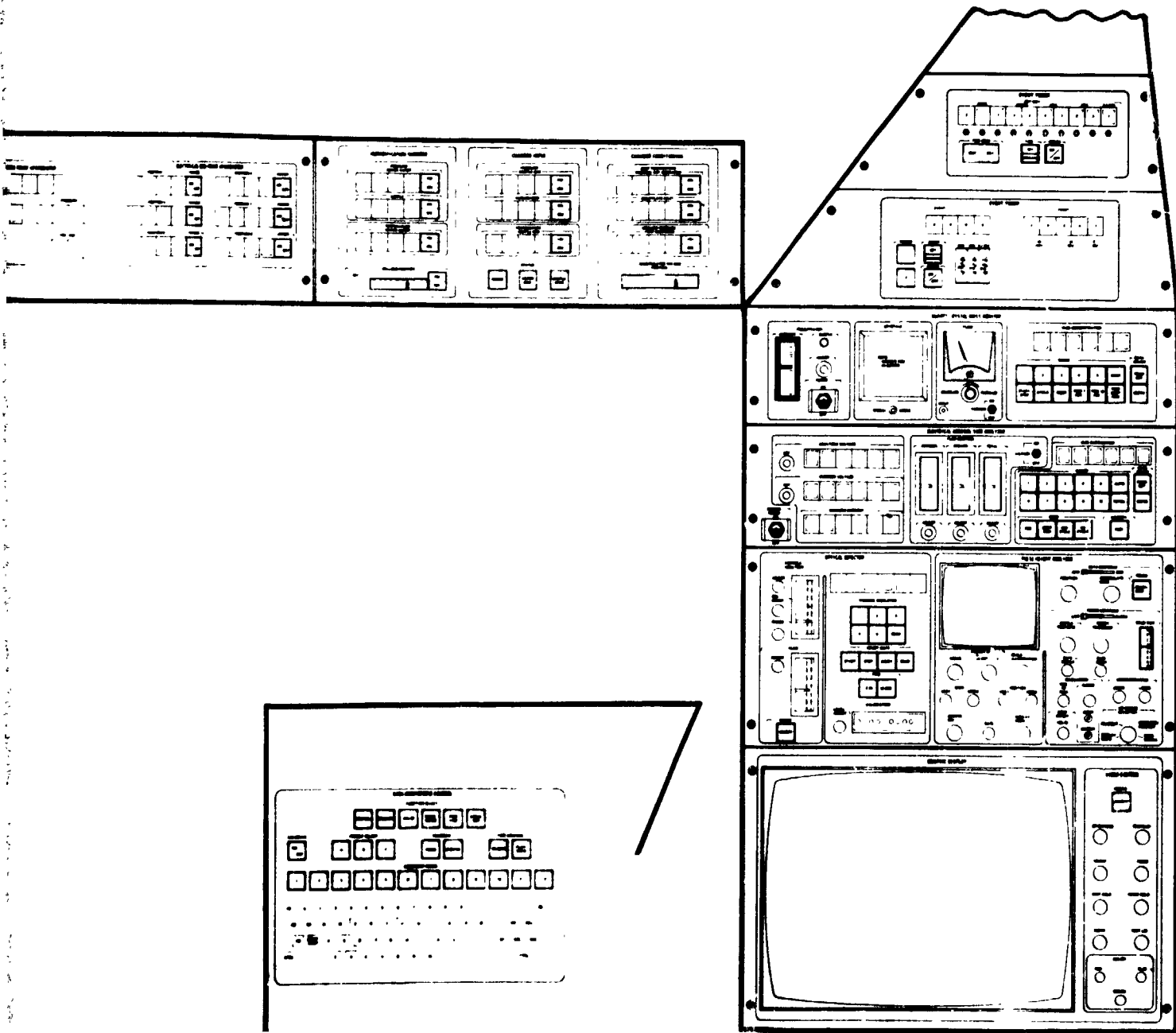
Figure 4-8. Continuous Flow Diffusion Chamber (Sheet 1 of 2)
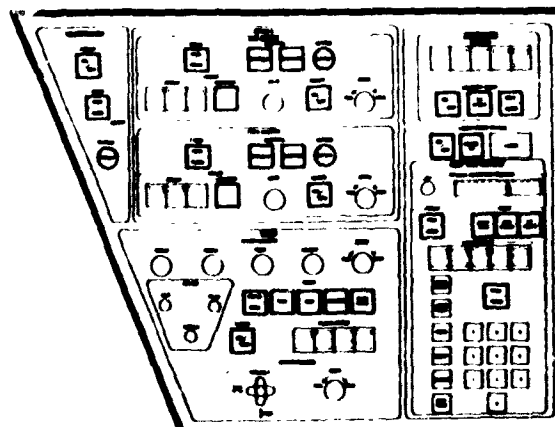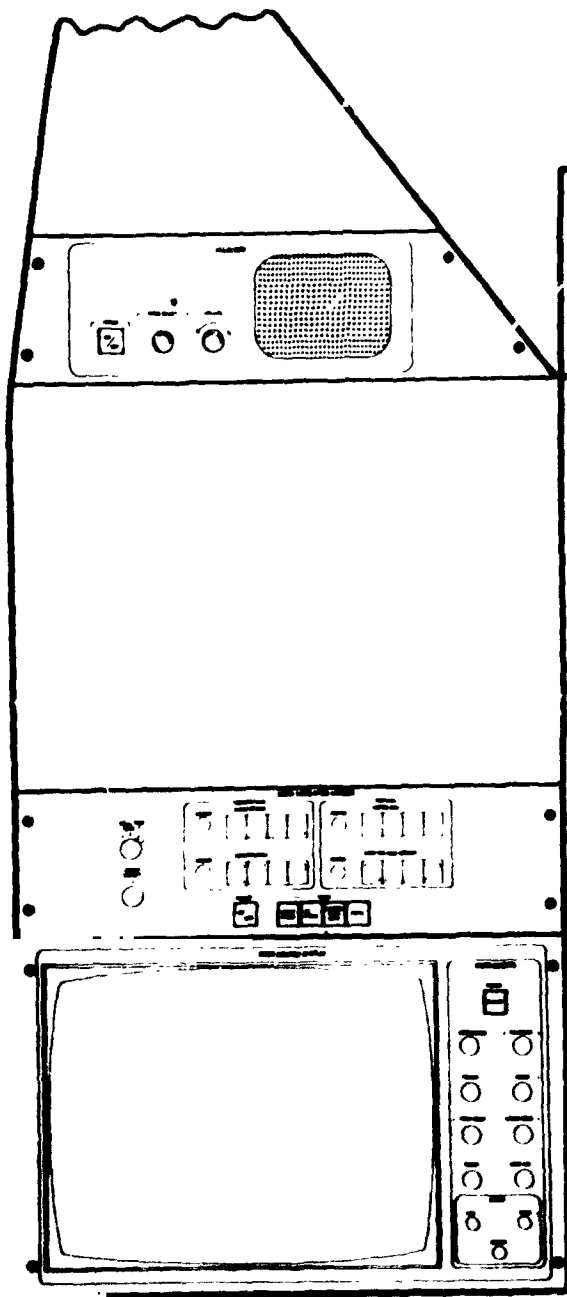
Figure 4-8 (Sheet 2 of 2)

Figure 4-9. Earth Simulation Chamber Configuration (Sheet 1 of 2)
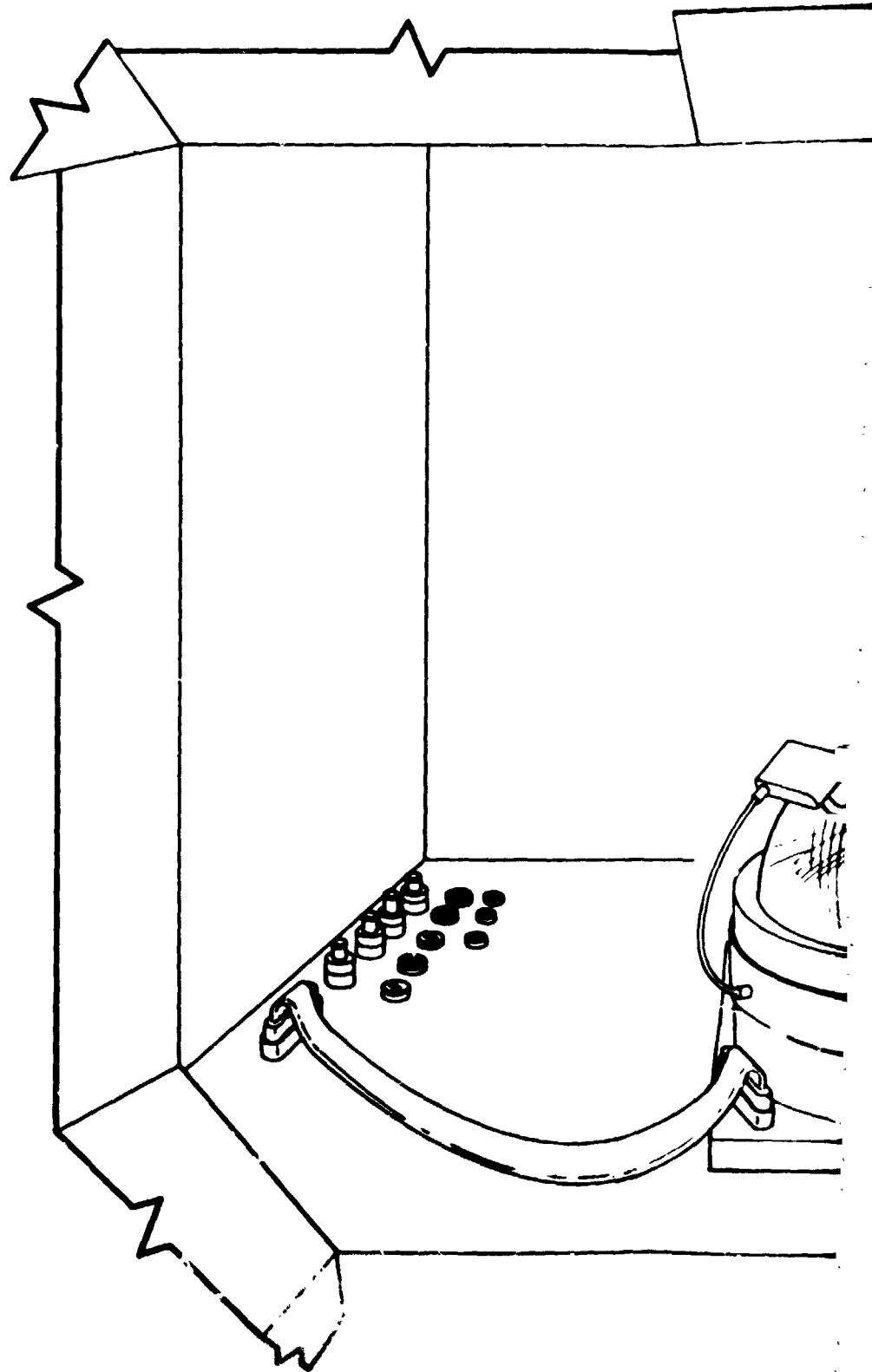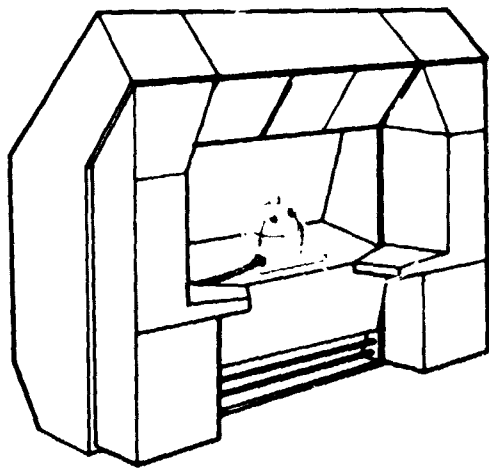
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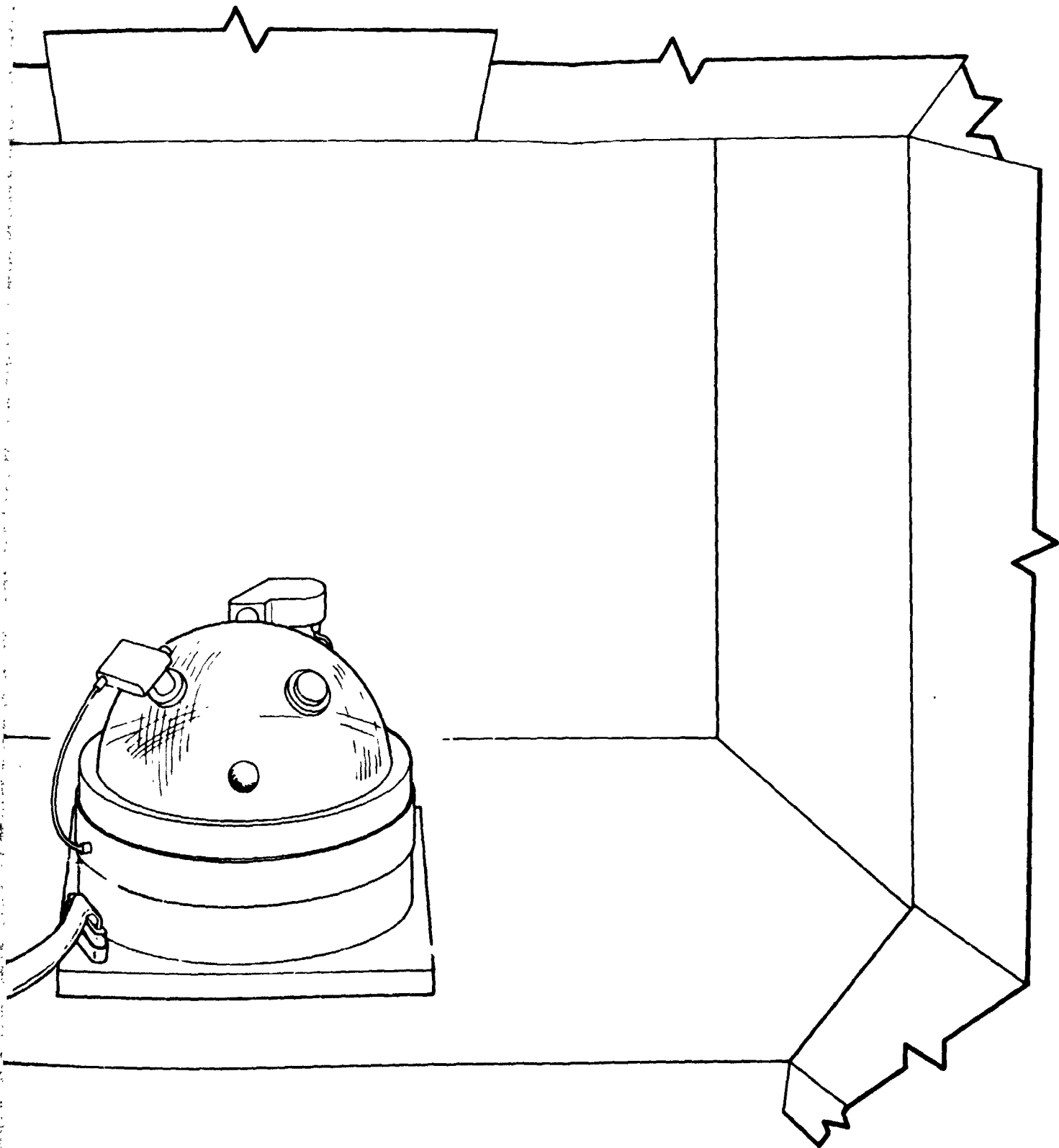
Figure 4-9 (Sheet 2 of 2)

Particle Generator Subsystem

This subsystem is located behind its control rack at the top of the left control panel. The five major generators will be permanently mounted here. The spray atomization and powder dispersion generators are not permanently mounted but stored in the lower left side storage cabinet. These units are plug-in units and will be attached to the nuclei conditioning chamber at the back of the work surface when required for the experiment.

Data Management Subsystem

The master control assembly is located in the lower half of the right control console. The teletype keyboard is located on the right keyboard shelf with the data/graphics display CRT directly behind it. All interface electronics, signal conditioning and control processor electronics are located in the lower half of the right cabinets. The video/monitor is located directly behind the left keyboard shelf with its controls on the left keyboard. The timing devices are located at the top of the right control console with the intercom unit on the top of the left control console.

Particle Detector and Characterizer Subsystem

This total subsystem will not fly on every mission and most of the individual assemblies are standard panel mounted and are interchangeable. The micro-porous filter and cascade impactor are not panel mounted but stored in the lower left storage area along with their respective filter and slide storage containers. The filter and impactor are removed from the storage and attached to the working surface next to the chamber when they are required for the experiment. They are then stored in their respective areas when not in use. The dewpoint indicators are permanently mounted along the front of the console directly over the working area. The scatterometer, drop size distribution meter and the liquid water content meter which are all similar in operation using laser device are all attached to or are inside the chambers. The controls for these devices require input to the computer for operation and are therefore located on the left keyboard shelf. The remainder of the subsystem assemblies are panel mounted in standard racks and are inter-changeable, depending on the mission, in the upper half of the right control cabinet.

Experiment Chambers and Aerosol Conditioning Subsystem

Each mission will require only one experiment chamber which is mounted in the center of the work area. All other subsystems interface with it. The expansion system required by the expansion chamber is located directly below the center of the work area under the chamber and can be removed when the expansion chamber is not required. The nuclei conditioning chamber is directly next to it on the opposite side of the humidification chamber. These are shown in Figure 4.2. The chamber controls are all mounted on standard racks which are interchangeable depending on which chamber will be used on the mission. These controls are located directly above the video monitor on the left control cabinet. The nuclei conditioning chambers controls because it is required on every flight are mounted on the same rack with the gas supply controls directly above the chamber controls.

Optical and Imaging Devices Subsystem

All of the optical and imaging devices are stored in the lower left storage container during launch and are attached directly to the chambers during the experiment. All of the controls of this subsystem, because they are the most often used, are mounted permanently on the left keyboard shelf.

4.3.2.4 Design Missions

The Cloud Physics Laboratory has been defined to support the envisioned range of atmospheric cloud research experimentation. The baseline capability of the laboratory includes support of single and multiple experiment classes utilizing a single cloud chamber. The baseline duration of laboratory missions are 7 days. Extended duration of laboratory missions will be up to 30 days. The laboratory has been designed for operation as a portion of the total payload for the Spacelab. Expanded operational capability is to be achieved by multiple laboratory (up to four) installation within a Spacelab.

4.3.2.5 Design Life

The Cloud Physics Laboratory has been defined for the performance of 20 missions and a total of 1,500 experiment hours over an operational life of 10 years (ground refurbishment permitted between missions).

4.3.2.6 Mission Success

The Cloud Physics Laboratory has been defined for a high probability of mission success. Mission success will be determined by proper functioning of the laboratory and its subsystems. This probability of mission success will be established based on a cost effectiveness tradeoff. This level of mission success will be assured by component and subsystem reliability, redundancy, etc. Mission success does not require successful completion of each individual experiment of an experiment mission.

The Cloud Physics Laboratory subsystem designs are based on a safe life concept for all subsystems where failure could cause hazards to the personnel, other payloads, the Spacelab, or Shuttle Orbiter. All other subsystems are based on a fail-safe concept with redundancy used only to achieve mission success goals or to reduce cost.

4.3.2.7 Crew Size

The design of the cloud physics laboratory is predicated on Space Laboratory module personnel as defined in Table 4-2.

Table 4-2

CREW SIZE

Mission Type	Payload Carrier	Total Number of Crewmen		Remarks/Skills Required
		1 Shift	2 Shifts	
Sortie (7-Day Mission)	Spacelab with/ without pallet	2 or 3, plus 2-4 PS's in Lab (7 total max)	3, Plus 4 Max PS's in Lab (7 total max)	Two interface systems specialists required to support 2-shift operation. Cross-training may allow total of 3 operations crewmen.

4.3.2.8 Weight, Power, and Volume

The Cloud Physics Laboratory weight, power, and volume* are given by experiment class in Table 4-1.

Weight

The total weight of the Cloud Physics Laboratory and expendables, all with suitable weight margins, have been established consistent with good engineering design practice and achieving required safety at low cost. Safety factors and design margins have been established sufficiently large to minimize costly verification and qualification efforts.

Power

The total peak and average power of the Cloud Physics Laboratory, with suitable power margins, have been established consistent with good engineering design practice. Where appropriate, equipment and subsystems directly compatible with the Spacelab have been utilized. The laboratory power control subsystem incorporates safety features to eliminate hazards to personnel and to prevent laboratory failure from disrupting operation of other payloads or the Spacelab. Safety devices and design margins are provided to minimize costly verification and qualification efforts.

Volume

The volume of Cloud Physics Laboratory has been established to accommodate equipment and subsystems defined for the baseline concept, including expendables and to provide sufficient free volume to permit efficient and effective ground refurbishment. Sufficient volume has been allocated for growth to the extended duration mission and incorporation of advanced equipment and subsystems (including provision for their storage and ground refurbishment).

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*The weight, power and volume of laboratory was established with the primary consideration of low total project cost. Reduction in the laboratory characteristics are obtainable at increased cost necessitated by expended design, development, test and evaluation effort, production unit cost and spares, replacement and maintenance cost.

4.3.2.9 Autonomy (Level of Spacelab Support)

The Cloud Physics Laboratory will make efficient use of Spacelab support (i.e., power, communications, environmental control, etc.) consistent with simple laboratory to Spacelab interface and with minimum interference during payload integration activities.

4.3.2.10 Subsystems

All elements of the Cloud Physics Laboratory have been selected based on cost effectiveness evaluations involving consideration of design, development, manufacture, qualification, operation, spares allocation, and replacement project factors. Where cost effective, available subsystems, assemblies, and components will be used. These items are to include standard commercial equipment (upgraded for manned aerospace usage) and equipment developed for other programs/projects.

Thermal Control/Expendables Storage and Control

This subsystem includes all assemblies necessary to provide: (1) cooling of the cloud chamber, (2) cooling of all other CPL equipment within the CPL console; (3) humidification, storage, and equilibration of air and sample gases; (4) storage of sterile, deaerated water for use in the humidification process; and (5) storage of all expendable gases.

This subsystem includes the following major assemblies.
    A.   Thermal Control
    B.   Flow, Humidity and Pressure Control
    C.   Expendable Storage
    D.   Instrumenta'ion and Display
    E.   Expendables
    F.   Cleansing Purge and Vent

Particle Generator

This subsystem includes all generators required to produce liquid drops/ice crystals, both single and multiple, and all nucleating aerosols to perform the experiment classes. This includes the following assemblies:
    A.   Wire probe retractor liquid/ice drop generator
    B.   Water drop impeller liquid/ice drop generator

C.   Vibrating orifice liquid/ice droplet generator

D.   Evaporation/condensation aerosol generator

E.   Spray atomization nuclei generator

F.   Powder dispersion nuclei generator

G.   Particle injector and size conditioner

Data Management

The data management subsystem includes all the assemblies for recording,
computation, command, control, data transfer, and caution and warning
annunciation. It performs the information transfer internal to the laboratory
and the dissemination of this information to the user. It interfaces with the
Spacelab data management system. It includes the following assemblies:

A.   Control processor assembly

B.   Tape recorder assembly

C.   Master control assembly

D.   Signal conditioning electronics assembly

E.   Instrumentation and display assembly

F.   Expendables

Particle Detectors and Characterizers

This subsystem includes all detection devices required to determine
particle size and distribution as well as the nuclei mass and concentrations.
One or more of these detectors can be used as required by the experiment
class. This subsystem includes the following particle detectors and
characterizers:

A.   Optical particle counter

B.   Pulse height analyzer

C.   Condensation nucleus counter

D.   Microporous filters

E.   Quartz crystal mass monitor

F.   Cascade impactor

G.   Electrical aerosol size analyzer

H.   Scatterometer

I.   Liquid water content meter

J. Droplet size distribution meter

K. Optical thermoelectric dew point hygrometer

L. Electric dew point hygrometer

Experiment Chambers and Aerosol Conditioning

There are five basic cloud chambers utilized in microphysics research which are applicable to zero-gravity experiments. The continuous flow diffusion, static diffusion liquid, and static diffusion ice chambers operate on a thermal vapor diffusion principle to provide controlled supersaturated conditions. These chambers require thermally controlled surfaces which are water or ice covered. The expansion and general chambers require thermally controlled surfaces. These chambers are used to define the relative humidity, pressure, and temperature environment for the experiments.

In addition to the cloud chambers an earth simulation chamber will simulate certain aspects of planetary and solar convection with its attendant differential rotation. Also a nuclei conditioning chamber is utilized to store and condition nuclei for the various experiments.

This subsystem includes the following experiment chambers and aerosol conditioning assemblies:

A. Static diffusion liquid chamber

B. Static diffusion ice chamber

C. General chamber

D. Expansion chamber

E. Continuous flow diffusion chamber

F. Earth simulation chamber

G. Nuclei conditioning assembly

Console

The console provides the working space, storage (including the rack-mounted subassemblies), and work station for the CPL. It provides a central work area with control/display and equipment storage on either side of the work station. This subsystem includes the following assemblies:

A. Console support structure and subassembly

B. Power control and distribution

C. Console panels and drawer subassembly

Optical and Imaging Devices

This subsystem contains all optical devices used for observing the experiments and data recording. This includes all motion and still photography. It provides all lighting devices, focusing and magnification optics required to produce usable data both in situ during the experiment and from samples taken on slides or filters. Also included is the optical velocity-measuring instrumentation. This subsystem includes the following assemblies:

A. Cine camera (35 mm)

B. Still camera (35 mm)

C. Microscope, trinocular

D. Video camera assembly

E. Light source

F. Anemometer

G. Stereo microscope

H. IR microscope

I. Expendables

4.3.2.11 Growth

The baseline Cloud Physics Laboratory will include design provisions, if cost effective, for accommodation of advanced equipment and subsystems and for growth in mission duration up to 30 days. This growth can be provided by addition of an equipment rack assembly and/or tankage.

4.3.3 Operations

4.3.3.1 Mission Operations

The baseline assumption for mission operations for the Cloud Physics Laboratory is that communications and mission control will be through the Mission Control Center at Johnson Space Center (JSC).

4.3.3.2 Communications Network

The characteristics of the communications systems with the earth, as a function of operational data, are described in "Characteristics of Future Ground Network and Synchronous Satellite Communications System for

Support of NASA Orbital Missions* (for Planning Purposes Only)", OTDA,
September 1972 issue.

4.3.3.3 Data Management
The baseline assumption for the definition and management of data acquisi-
tion, processing, and handling is that they will be the responsibility of
Cloud Physics Laboratory mission integrator.

4.3.3.4 Experiment Payload Integration
The baseline assumption for Cloud Physics Laboratory integration is that
it will be the responsibility of Cloud Physics Laboratory mission integrator,
but will be carried out in many cases at locations including KSC and various
facilities (other NASA centers, other Government laboratories, universities,
industrial concerns, foreign users, etc.). This integration will be at the
complete laboratory level.

4.3.3.5 Mission Preparation
The baseline assumption for prelaunch mission preparation, including Cloud
Physics Laboratory refurbishment, final experiment mission definition,
prelaunch crew training, hardware and software experiment mission
compatibility, verification and checkout, is that it will be carried out at the
location or facility that is most cost effective.

4.3.3.6 Interface
Spacelab Module Interface
The baseline Spacelab module to Cloud Physics Laboratory interface will be
in accordance with the following documents:

    A. NASA/MSFC - Sortie Laboratory Users Guide (Interim Issue
        based on US Option)*

    B. NASA/MSFC - Sortie Laboratory Design Requirements,
        December 1972*

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*This document to be superseded by updated NASA reports as they become
available.

The CPL interfaces to the Spacelab, as presently defined make efficient use of the Spacelab resources to reduce CPL equipment. These interfaces, however, have been established in a manner to permit the greatest level of CPL autonomy and provide minimum interference in payload integration activities. The existing Spacelab/CPL interfaces are summarized in the following paragraphs. Additional interface data is included with the appropriate CPL subsystem descriptions in Section 5.

Structural Interfaces
- Console — The CPL console will interface with the Spacelab shell and floor structure. This present concept defines usage of the standard ERNO cabinetry thereby facilitating CPL installation and removal in an efficient manner.
- Thermal Control/Expendables Storage and Control — The air storage assembly (high pressure tankage) is presently to be installed and mounted external to the Spacelab on the conical surface. The present concept defines procurement of standard ERNO tankage (Spacelab extended duration air storage tankage) and associated flow control regulation, and mounting components. Use of this equipment eliminates CPL project DDT&E costs and enhances Spacelab integration. The external air tankage does necessitate use of a Spacelab shell "feed-through" for the air supply to the CPL.
- Thermal Control/Expendables Storage and Control — The Spacelab overboard vent is used for experiment expended sample "dump". Conditioning and flow control of the CPL necessitates a Spacelab shell "feed-through".

Power Interface
- The CPL will interface with both the unregulated 28 vdc and the 115/200 vac 3 phase, 400 Hz Spacelab power busses. The ERNO Spacelab converters required to condition the power for CPL usage have been identified. Use of these converters reduces CPL project DDT&E costs and simplifies this interface.

Thermal Interfaces

- Thermal Control/Expendables Storage and Control — The thermal capacitor/heat exchanger for cloud chamber thermal control interfaces with the 7°C Spacelab thermal control system coldplate. Additional Spacelab definition is required to formulate interface requirements.

- Thermal Control/Expendables Storage and Control — The cooling of all CPL equipment within the CPL console will be provided by the Spacelab avionic cooling system. The ERNO cabinetry is defined to include the ducting, and parts required. The air supply for cooling is to be provided by the Spacelab environment control system (ECS).

Data Management Interface

- The CPL data management subsystem interfaces with the Spacelab data management system. The physical aspects of this interface are relatively simple; operational aspects require additional detailed evaluation. The presently defined interface makes maximum use of the Spacelab capability and permits CPL equipment development and operation with a minimum of Spacelab equipment simulation.

The descriptive data in the above itemized documents represent the current Spacelab module interface definitions and are presented as reference data only as requirements are subject to change as design requirements of the Shuttle Orbiter and Spacelab module evolve from trade studies and design definition maturity.

4.3.4 Laboratory Growth Potential

The baseline CPL concept formulated by this study reaffirmed the results of an austere through advanced/comprehensive laboratory evaluation performed previously. Efforts to reduce project cost by utilization of commercial equipment, terrestrial laboratory equipment, or equipment of reduced tolerance/accuracy violated the guidelines for the project as did consideration of or reduction in laboratory automatic controls and/or the deletion of equipment. It was shown that significant cost savings could be achieved only by the elimination/deletion of equipment and that this approach was not cost effective in that it significantly reduced the experiment program and compromised the project objectives. This approach, furthermore, is not responsive to the desires of the scientific community.

The growth for the CPL has been evaluated from the standpoints of both
in ed mission duration and the incorporation of advanced/improved
subsystems.   Longer duration mission capability has been provided in the
baseline concept by inclusion of the required extended direction operating
life for CPL equipment. This capability can be provided without noticeable
impact on project cost due to the low operating life requirement, even con-
sidering long duration missions

The growth to longer duration mission involves incorporation for increased
expendables (gas samples, film, water, tape and possibly spare parts). The
additional sample air storage can be provided by the addition of additional
tankage, adjacent to the baseline (7 day) tankage on the conical section of the
Spacelab. Sample gases, water, film, and tape constitute a minor volume
that can be accommodated within the CPL. Extension of longer duration
missions will, however, result in increased weight for the CPL and influence
ground refurbishment, astronaut training and principal investigator scheduled
operations.

Since the CPL is envisioned for multiple mission reuse over an extended
duration (10 years), capability to incorporate advanced improved subsystems
was evaluated. This evaluation identified equipment desired for cloud micro-
physics research but not included in the baseline CPL because of state-of-the-
art technology status, development cost and/or development risk.   The
improved/advanced equipment includes:

    A.   Improved tolerance equipment for pressure temperature and dew
         point
    B.   Holography
    C.   Raman spectroscopy
    D.   UV water profile detector
    E.   Improved control expansion cloud chamber
    F.   Advanced IR microscope

A preliminary assessment of the CPL did not reveal any but geometric restric-
tions that would preclude incorporation of this equipment. Since it is not
possible to predict the shape, volume and access to the chamber required
by the equipment the CPL concept was not modified.

4.4 SCIENTIFIC COMMUNITY PARTICIPATION

The Cloud Physics Laboratory project, because of the nature of the research
it is to conduct and the ultimate application of that research, involves both
participation of the scientific community (individual cloud physics researchers
scientists involved in meteorology, cloud modeling and field experimentation,
governmental agencies, university research groups, commercial/industrial
organizations and international entities) and applications groups (weather
forecasters and weather control and modification organizations operating
at the direction of or under contract to the federal government, state govern-
ments, local governments, government agencies, large agricultural land-
holders, lumber companies, the fishing industry, maritime shipping,
regional recreational groups, airport operators and other private concerns
whose success is dependent upon weather and climate conditions). At the
present stage of the project primary effort has been directed to the scientific
community participation. Contact with application groups has not been
actively pursued other than the creation of awareness of the project through
NASA press releases, wide dissemination of project summary reports,
presentation of technical papers at national meetings of professional
societies, and publication of technical papers in national publications. The
scientific community has, as previously described, participated in the
formulation of the laboratory experiment program and laboratory concept
formulation. Their continued participation is envisioned in all project
phases and is described in the following section. The applications groups,
while not direct participants in the laboratory project, are still vital to
project success. Their involvement and support of the laboratory project
is predicated on their desire and need of improved weather prediction
capability and on their acceptance of weather modification and control as a

viable technique to reduce loss of lives and property damage and to improve/
enhance the attainment of weather and climate objectives for both the general
public or specific economic advantages. In this context, applications groups
support of the laboratory project is dependent on their understanding that
cloud physics research is the "leading edge" technology in the attainment of
weather modification and control, and that the orbital laboratory is a
necessary and vital facility for the conduct of cloud physics research.

4.4.1 Project Participation

As described in Section 3, the scientific community has been involved since
project inception. Their contributions have provided the basis for the
experiment program and the laboratory concept, and is envisioned for the
subsequent project phases and related supporting research and technology
development efforts. The following paragraphs delineate the scope and major
function of the scientific community by project phase.

4.4.1.1 Laboratory Definition Study (Phase A)

The scientific community performed tasks to refine and improve the experi-
ment program definitions, to establish the methodology for and perform the
initial determination of experiment mission priority, and to revise and
update laboratory experiment equipment requirements. These study efforts
provided the scientific basis for the laboratory concept refinement and
laboratory subsystem tradeoffs.

4.4.1.2 Laboratory Preliminary Design Study (Phase B)

The support of the scientific community in this project study will include
formulation of specific experiment mission definitions, assessment of
laboratory concept accommodation of experiment missions, and support
of end item specifications for cloud chambers, droplet generators, and
particle detectors and characterizers.

4.4.1.3 Technology Development Efforts

The technology development of cloud physics research related equipment will
involve scientific community participation. This equipment includes all

cloud chambers, the conditioning chamber, the environment controllers, and the liquid and aerosol generators. The development of this equipment requires the scientific community expertise in support of manned space equipment manufacturing experience.

In addition, selected members of the scientific community are to perform efforts related to "key" project factors, planning for subsequent scientific community participation, coordination/communication with applications groups and providing scientific guidance to the MSFC project personnel.

4.4.1.4 Laboratory Development and Production (Phase C/D)

The scientific community will support the laboratory contractor during the project hardware development and production. Their efforts will primarily be an extension of the efforts performed for laboratory equipment development and involvement in the integration of this equipment into the laboratory.

4.4.1.5 Laboratory Operations [Phase D (Operations)]

The laboratory flight operations project phase is the principal area of scientific community participation.

During this phase principal investigator teams will be identified for specific laboratory missions. These teams will be selected and the flight mission assignments made by a select group of senior cloud physicists, cloud modelers, field experimenters, and applications group representatives. The principal investigator teams will formulate the experiment mission objectives and timelines, provide astronaut training coordination, support flight operations, conduct astronaut experiment debriefing, perform experiment mission data reduction and evaluation and prepare the experiment mission technical report. The laboratory operations contractor will support the principal investigator teams in laboratory refurbishment/repair, laboratory equipment installation/configuration, laboratory checkout, and laboratory integration with Spacelab.

4.4.2 Selection Procedure (Tentative)

The experiment missions and the principal investigator or principal investigator team will be selected by NASA in accordance with procedures established for scientific participation in the Spacelab project.

Though the process by which experiments are identified and selected for flight has not been firmly established at the present time, a typical flow is shown in Figure 4-10. The procedure will be initiated by preparation and submittal of an experiment proposal. At a minimum, the proposal would contain the following types of information in sufficient depth to permit a preliminary evaluation by an appropriate NASA experiment review board:

A. Experiment description, objective, and rationale.

B. Desired flight date and duration.

C. Resource requirements for operational support (power, work space, crew skills, data transmission, etc.).

D. Potential hazards and contamination sources.

E. Special ground support equipment and facilities.

F. Status of experiment development.

G. Spacelab support equipment needed.

Criteria for principal investigator experiment mission selection will be established during workshop activities involving the NASA, representatives of the atmospheric cloud physics community, and the cloud physics laboratory mission integrator.

Criteria will include scientific priority, achievability, and zero-gravity applicability factors, in addition to factors associated with scheduling for payload selection (experiment mission planning and timeline, astronaut training, experiment mission support, etc.). The experiment mission selection will further depend on the proposed principal investigator or principal investigator team. Preeminence in the area of experimentation and availability for experiment mission support activities will be major consideration.
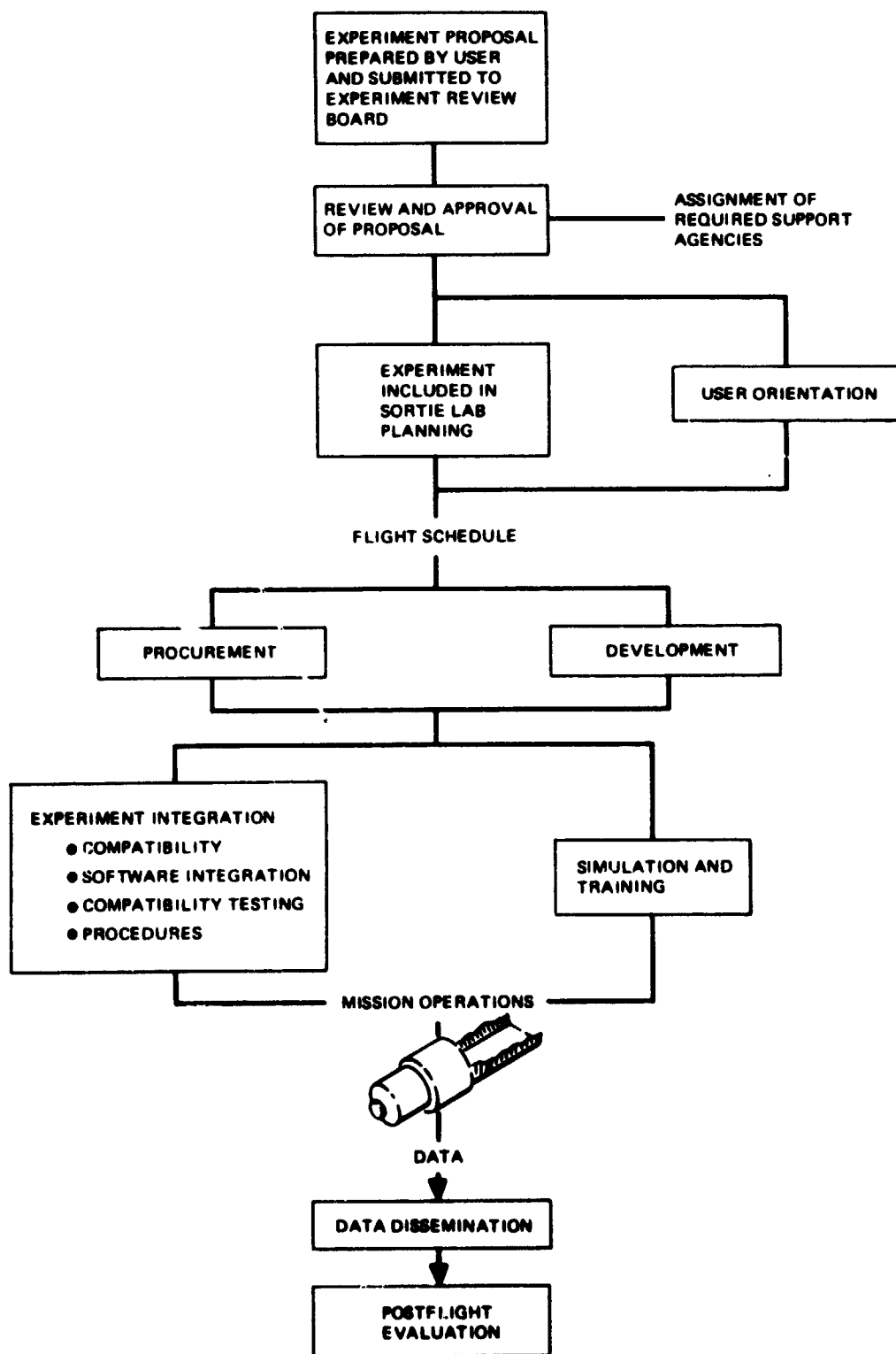
Figure 4-10. Typical Experiment Integration Procedure

Section 5
CLOUD PHYSICS LABORATORY SUBSYSTEMS

The Cloud Physics Laboratory consists of the following subsystems:

A. Thermal control/expendables storage and control

B. Particle generators

C. Data management

D. Particle detectors and characterizers

E. Experiment chambers and nuclei conditioning

F. Console

G. Optical and imaging devices

The subsystems, their assemblies, and lower-level elements have been selected based on cost effective evaluations involving consideration of design, development, manufacture, qualification, operation, spares allocation, and replacement factors. Available subsystems, assemblies, and components, including commercial equipment (capable of being upgraded for manned aerospace usage) and equipment developed for other payloads/projects have been evaluated and defined to reduce total project cost.

The following sections define the individiual subsystem's equipment, the use by experiment class, and the weight, power, and volume characteristics. Where appropriate this information is supplemented by block schematics and detail design features of specific equipment. Subsequent sections of this report contain selected subsystem supportative analysis used to establish the subsystem elements, and definitions of Supporting Research and Technology (SRT) required.

5.1 THERMAL CONTROL/EXPENDABLES STORAGE AND CONTROL
This subsystem includes all assemblies and components necessary to provide the following CPL services:

A. Cooling of the cloud chamber(s) with a closed-loop fluid system with ultimate heat rejection to the Spacelab thermal control system through an interface heat exchanger.

B. Cooling of all other CPL equipment within the CPL console using air supplied by the Spacelab avionic cooling system.

C. Humidification, storage, and equilibration of air and sample gases within a variable volume chamber for later, scheduled withdrawal to the cloud chamber(s).

D. Storage of sterile, deaerated water for use in the humidification process.

E. Storage of all expendable gases (air and sample gases) including an excess quantity for system purging and cleaning.

F. Installation of necessary instrumentation sensors and definition of console displays.

This subsystem is permanently mounted in the console except for the expendable gas storage which is mounted outside the Spacelab. The subsystem will be flown on every experiment mission of the CPL. This subsystem includes the following assemblies:

A. Thermal control

B. Flow, humidity, and pressure control

C. Expendables storage

D. Instrument and display

E. Expendables

F. Cleansing, purge, and vent

Weight, power, and volume are given by assembly on Table 5-1.

5.1.1 Thermal Control

Equipment will be provided to supply cooling to the cloud chamber thermo-electric modules and to all console-mounted CPL avionic and support equipment. See Figure 5-1 for schematic of this assembly.

5.1.1.1 Cloud Chamber Cooling Subassembly

The cooling subassembly will provide the means to transport heat from and maintain temperatures in the cloud chambers. Heat will be removed from the chamber by liquid water coolant that in turn will reject heat to a 7°C Spacelab coldplate through a heat exchanger. The heat exchanger will contain

Table 5-1

SAMPLE GAS STORAGE, PREPARATION, AND FLOW CONTROL FEATURES

Assembly	Weight (kg)	Volume (m^3)	Power, Maximum Operating (watts)	Power, Nominal Operating (watts)	% Usage Experiment Time	Average Power (watts)
Thermal Control	49.8	0.108	100	100	100	100
Flow, Humidity, and Pressure Control	119.2	0.340	90	90	20	18
Expendables Storage	253.8	0.724	-	-	-	-
Instrumentation and Display	14.5	0.004	-	-	-	-
Expendables	75.3	-	-	-	-	-
Cleansing Purge and Vent Subassembly	35.2	0.012	-	-	-	-
Totals for Experiment Classes 1 through 21	547.8	1.187	190	190	-	118

53
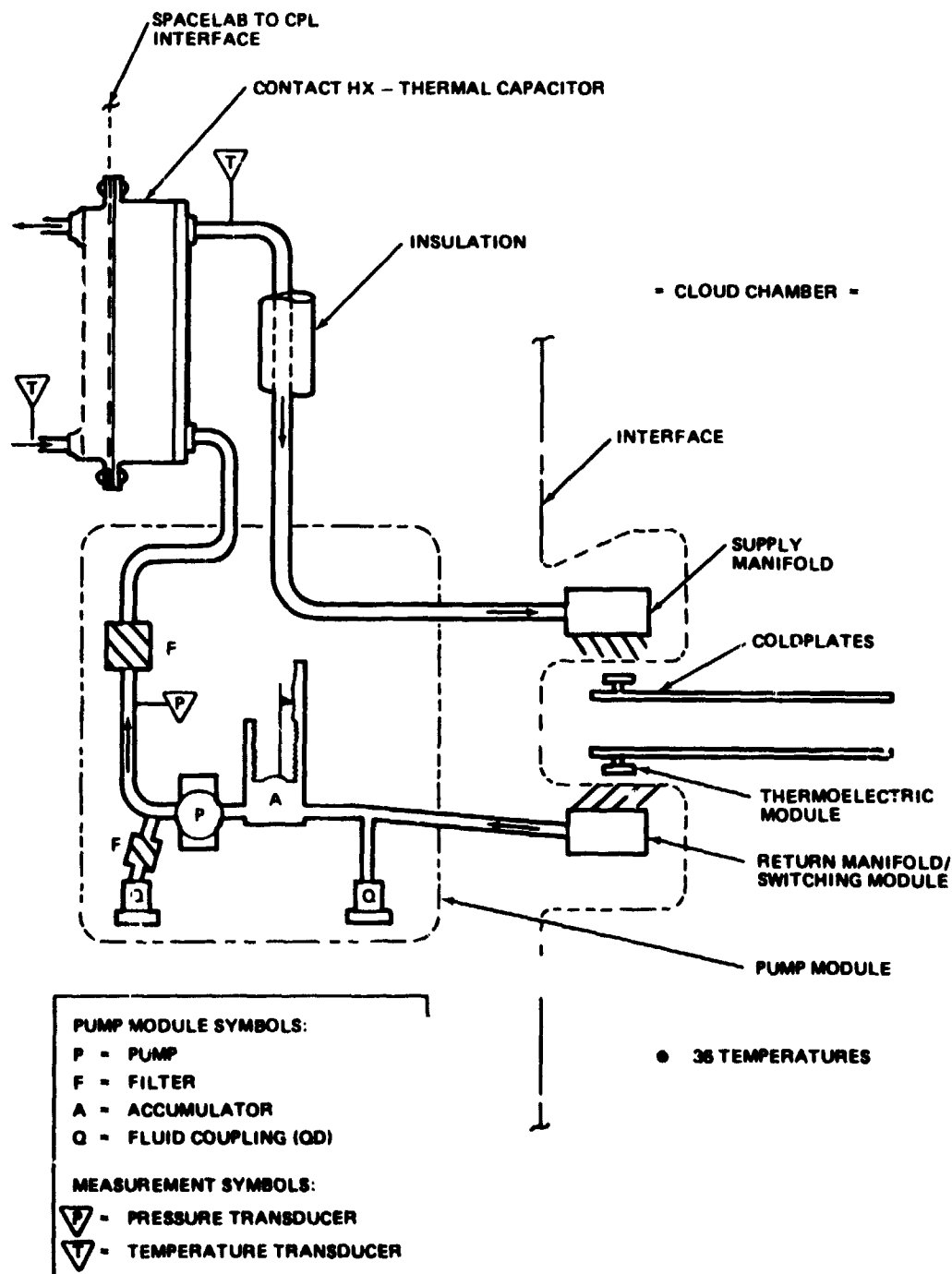
Figure 5-1. Cloud Chamber Cooling Subassembly

a phase-change material that adsorbs excess cloud chamber heat during operation at a temperature less than -32° C. The heat removal to achieve -40 C in the cloud chambers will be accomplished by using thermoelectric (TE) cooling within the cloud chamber and is described in the cloud chamber subsystem.

5.1.1.2 Contact Heat Exchanger — Thermal Capacitor

This heat exchanger will provide a means to transport heat picked up by the coolant water to the Spacelab 7° C coldplate. It also will provide a phase-changing capacitor to adsorb thermoelectric module heat in excess of 150 watts for periods of time that are dependent upon TE module efficiency and ambient refrigeration load.

5.1.2. Flow, Humidity, and Pressure Control

Generation of humid gas samples and control of the flow and pressure of the samples during transfer to the cloud chamber will be managed by the humidification subassembly and the water storage and supply subassembly. See Figure 5-2 for schematic of the assembly.

5.1.2.1 Humidification Subassembly

The humidification subassembly (1) provides a water vapor source; (2) mixes proper proportions of water vapor, air, and sample gases; (3) equilibrates the mixture at Spacelab ambient temperature and at the proper pressure and humidity; and (4) is utilized during the purging and cleaning operations between experiments. The subassembly will be comprised of a wick evaporator, a valve module and a humidification chamber.

5.1.2.2 Water Storage and Supply Subassembly

The water storage and supply subassembly will supply deaerated, sterile water at constant pressure to the wick evaporator and, when required, to the cloud chambers.

5.1.3 Expendables Storage

Expendables storage will include all equipment (tanks, valves, plumbing, etc.) for storing and distributing sample gases and clean air for test and cleansing. See Figure 5-3 for schematic of equipment.
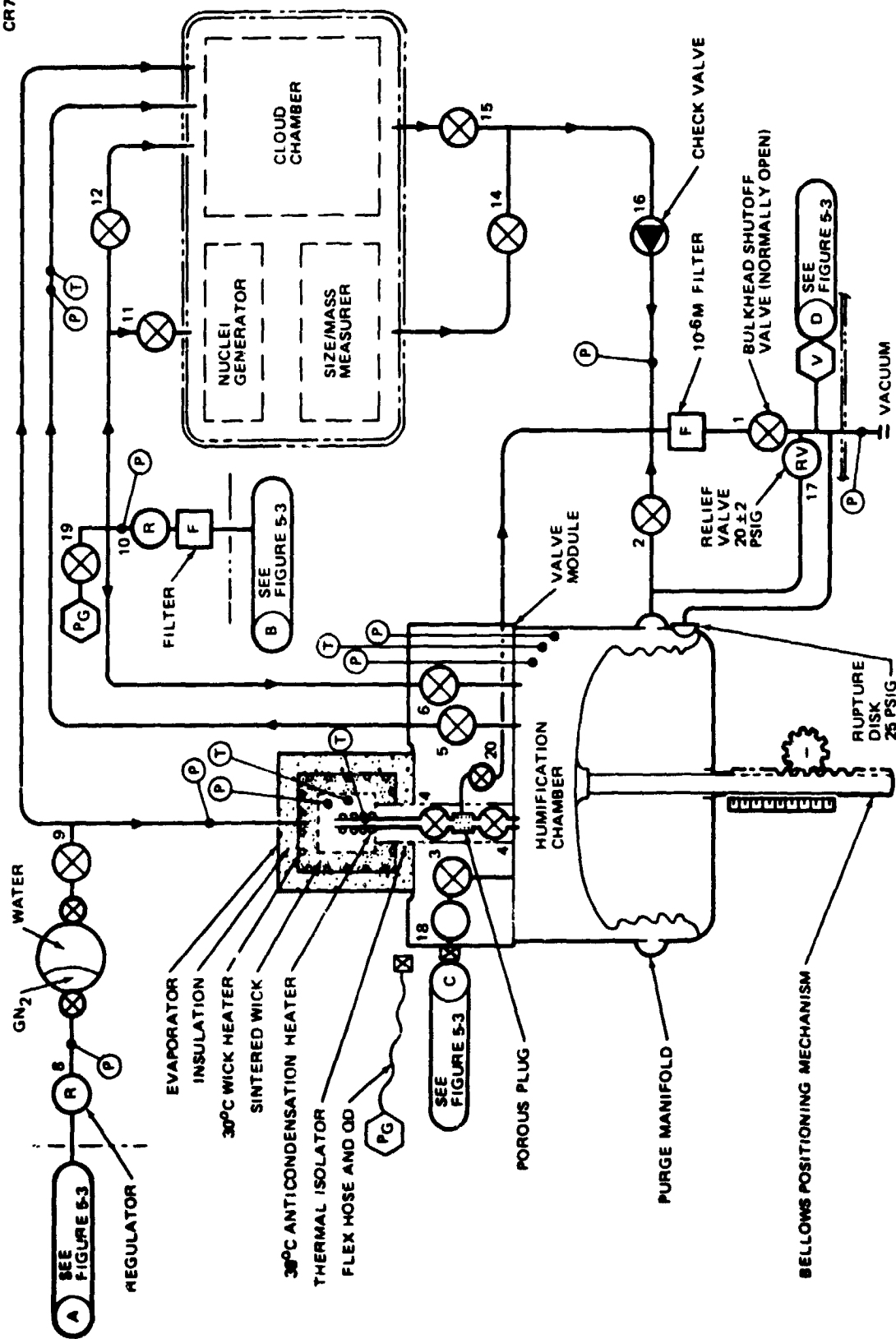
Figure 5-2. Flow, Humidity, and Pressure Control
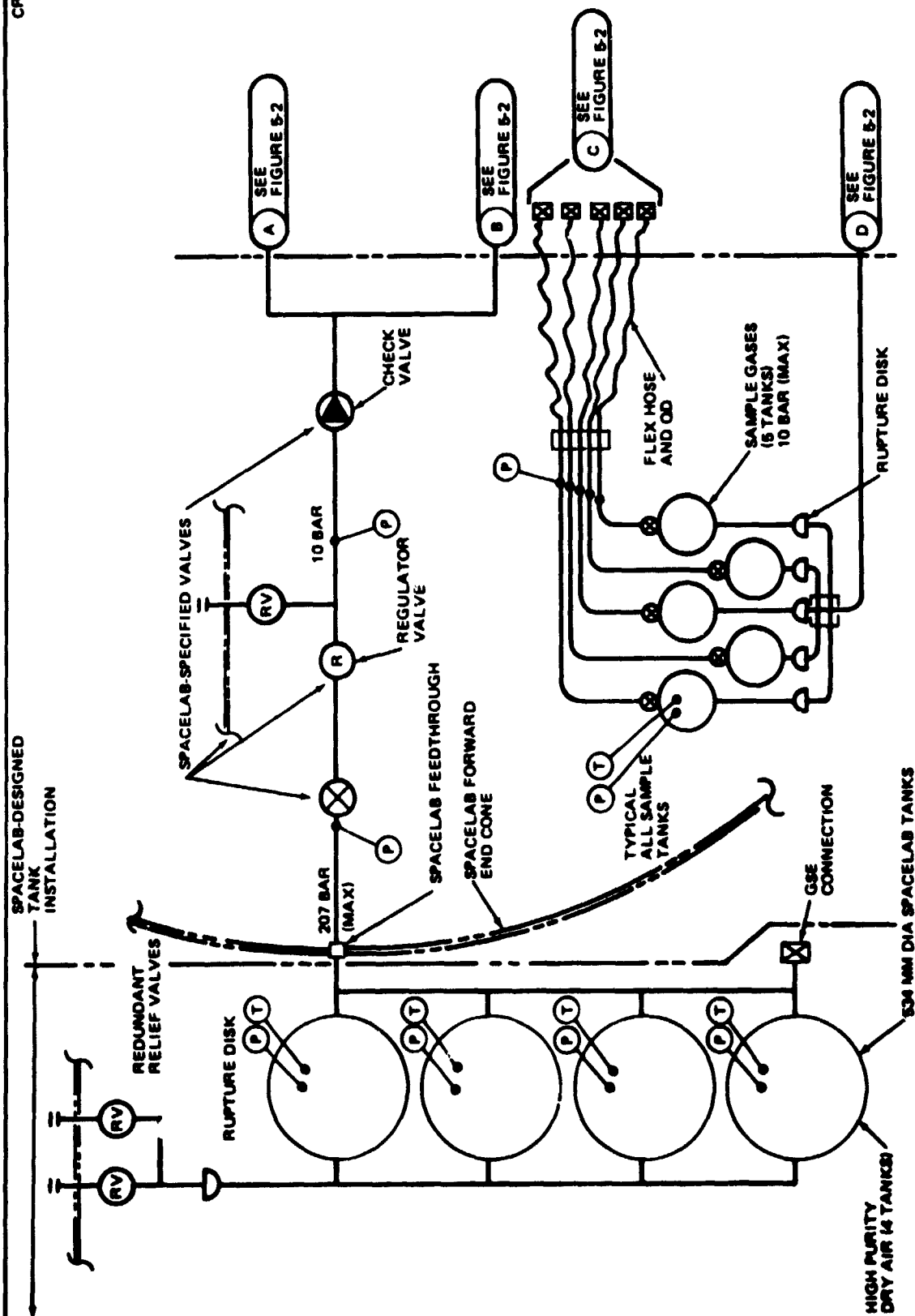
Figure 5-3. Expendables Storage

5.1.3.1 Dry Air Storage Subassembly

The dry air used as an additive to test samples and for cleansing purge will be stored externally to the pressurized Spacelab cabin on the forward cone. The Spacelab-designed tank installation will be used in its entirety, including tanks, valves, rupture disks, plumbing, support structure, and a spare feedthrough connection to internal CPL plumbing. Four tanks will be procured to Spacelab specifications. These tanks are 534 mm in diameter and will supply the total usable air mass of 69.4 kg required for a 7-day mission. The tanks will be fabricated of high-strength maraging steel and designed to safety factor of four times the limit pressure of 2.07×10^7 N/m^2. They will have a protective coating to resist external surface corrosion and will be enclosed within meteoroid shields.

5.1.3.2 Sample Gas Storage Subassembly

The various sample gases used in test gas preparation will be stored inside the console in separate 203-mm-diameter tanks. The baseline installation will have provisions for five tanks. Preservation of CPL cleanliness will be managed by the use of separate flexible hoses and quick disconnects (QD's) to connect to the valve module (VM) test port. (The VM test port QD and internal valving will be purged prior to a change to a different test gas.)

5.1.4 Instrumentation and Display Assembly

Pressure and temperature transducers will be used throughout the thermal control/expendables storage and control subsystems to monitor subsystem status and performance.

5.1.5 Expendables

Air, water, and sample gases (types yet to be determined) are expended during all experiment period. Air for experiment use and for cleansing purge will be particulate-free and dry to a dew point of -55° C or less. Sterile, deaerated water will be used to fill the water tank. No biocides will be added in order to prevent contamination of the evaporator wick.

5.1.6 Cleansing Purge and Vent Assembly

The cleansing purge and vent assembly will include: (1) all plumbing, valves, regulators, filters, etc., used to transport dry air from the dry air storage assembly interface to the humidification chamber and cloud chambers; (2) all plumbing and other components used to vent the waste gas samples; and (3) the test sample gas line from the humidification chamber to the cloud chamber.

5.2 PARTICLE GENERATOR

Several types of generators will be required in the proposed experiments. These will vary from hygroscopic NaCl particulates which typify many forms of natural nuclei in the atmosphere to large water droplets or ice crystals to study growth habits or collision breakup. These generators are of fundamental importance to the total experiment program. The generators must be adapted for operation in a low-gravity condition and functionally optimized for the specific experiment requirements of quantity, droplet size, and production rates.

Table 5-2 is a summary of equipment required by experiment class. Not all equipment indicated by class will necessarily fly on every mission. This subsystem includes the following assemblies:

    A. Wire probe retractor
    B. Water drop impeller
    C. Vibrating orifice
    D. Evaporation/condensation aerosol generator
    E. Spray atomization
    F. Powder dispersion
    G. Particle injector and size conditioner

Weight, power, and volume are given by assembly in Table 5-3 and by experiment class in Table 5-4.

5.2.1 Wire Probe Retractor Generator

When a wire is pulled rapidly out of a fluid, it pulls a filament of the fluid out from the surface. When the filament reaches a certain length, it will break off at the ends and contract to form a droplet. The size of the droplet is determined by the dimensions of the filament which are in turn controlled

Table 5-2

EQUIPMENT LIST BY EXPERIMENT CLASS

Experiment Class	Particle Injector and Size Conditioner	Powder Dispersion	Spray Atomization	Evaporation/Condensation Aerosol Generator	Vibrating Orifice	Water Drop Impeller	Wire Probe Retractor
1. Condensation Nucleation	X		X	X			X
2. Ice Nucleation	X		X	X	X		X
3. Ice Multiplication	X	X		X			X
4. Charge Separation	X		X				X
5. Ice Crystal Growth Habits	X			X	X	X	X
6. Scavenging	X		X		X	X	X
7. Riming and Aggregation							X
8. Droplet-Ice Cloud Interactions							X
9. Homogeneous Nucleation						X	X
10. Collision-Induced Freezing							
11. Saturation Vapor Pressure							
12. Adiabatic Cloud Expansion	X	X	X	X	X		
13. Ice Nuclei Memory		X	X	X			X
14. Terrestrial Expansion Chamber Evaluation		X	X	X	X		X
15. Condensation Nuclei Memory		X	X		X		X
16. Nuclei Mul'iplication							
17. Drop Collision Breakup						X	
18. Coalescence Efficiencies						X	
19. Static Diffusion Chamber Evaluation		X	X	X			X
20. Unventilated Droplet Diffusion Coefficients		X	X	X			

Table 5-3

PARTICLE GENERATOR SUBSYSTEM FEATURES BY ASSEMBLY

Assembly	Weight (kg)	Volume (m³)	Power Maximum Operating (watts)	Power Nominal Operating (watts)	% Usage Experiment Time	Average Power (watts)
Wire Probe Retractor	15	0.02	20	20	10	2
Water Drop Impeller	8	0.01	18	18	10	1.8
Vibrating Orifice	15	0.015	75	75	15	11.25
Evaporator Condenser	25	0.03	275	275	10	2.75
Spray Atomizer	8	0.01	11	11	5	0.55
Powder Dispersion	8	0.01	2	2	5	0.1
Particle Injector and Size Conditioner	12.05	0.026	85	85	60	51.0

Table 5-4

PARTICLE GENERATOR SUBSYSTEM FEATURES BY EXPERIMENT CLASS

Experiment/Class	Weight (kg)	Volume (m³)	Maximum Operating Power (watts)	Average Power (watts)
1	25	0.03	275	27
2	63	0.075	466	92
3	48	0.06	391	81
4	23	0.03	123	55
5	15	0.02	105	53
6	79	0.095	486	94
7	15	0.02	105	53
8	38	0.045	191	65
9	15	0.02	20	2
10	23	0.03	38	4
11	15	0.02	20	2
12	56	0.065	446	90
13	41	0.05	286	28
14	41	0.05	286	28
15	56	0.065	361	39
16	46	0.055	106	14
17	23	0.03	38	4
18	18	0.03	38	4
19	41	0.05	286	28
20	56	0.07	296	30
21	0	0	0	0

by the diameter of the wire, the angle that the wire makes with the surface of the fluid, and the depth of penetration of the wire into the fluid. The motion of the linear actuator moves the push rod and attached wire with amplitude determined by the size of the current pulse from the dual-pulse generator. The motion of the wire out of the water surface causes the droplet to form on the outgoing stroke in the manner described above. A hood is used to create a charge controlling electric field in the region where the droplets are formed. The dual-pulse generator is used to drive the linear actuator to form the droplets and to initiate the high-voltage pulse generator to charge the droplets. Figure 5-4 is a block diagram of the wire probe retractor generator.

5.2.2 Water Drop Impeller Liquid/Ice Drop Generator

A water droplet impeller is used to provide small volumes of liquid with variable droplet velocity. A linear actuator dispenses the liquid and the initial droplet velocity is controlled by the rate of actuation. A quantitative syringe is used as a repeating dispenser. The pushbutton dispenser discharges 1/50th of the syringe's capacity on command. Figure 5-5 is a block diagram of the water drop impeller generator assembly.

5.2.3 Vibrating Orifice Liquid/Ice Droplet Generator

This instrument produces droplets through the controlled breakup of a cylindrical liquid jet by a vibrating orifice. A cylindrical liquid jet is basically unstable and naturally tends to break into droplets. Left uncontrolled, the breakup process produces nonuniform droplets. However, by applying a periodic disturbance of an appropriate frequency on the liquid jet the breakup process can be controlled. In the controlled breakup regime, exceedingly uniform droplets are obtained. The standard deviation is typically 1 percent of the mean droplet diameter. Further, since each cycle of the disturbance produces precisely one droplet, the volume of the individual droplet is given by the ratio, Q/f, where Q is the volumetric liquid flow rate through the orifice, and f is the frequency of the applied disturbance.

This instrument can also be used to produce nuclei through the production of aerosols. If a liquid solution containing a nonvolatile solute in a volatile solvent is sprayed through the vibrating orifice, and the solvent is allowed to evaporate

WATER

DUAL-
PULSE
GENERATOR

VALVE

POWER

HIGH-
VOLTAGE
PULSE
GENERATOR

WIRE
PROBE
RETRACTOR

CLOUD
CHAMBER

V

SWITCH

LINEAR
ACTUATOR

CONTROL
SIGNAL

POS
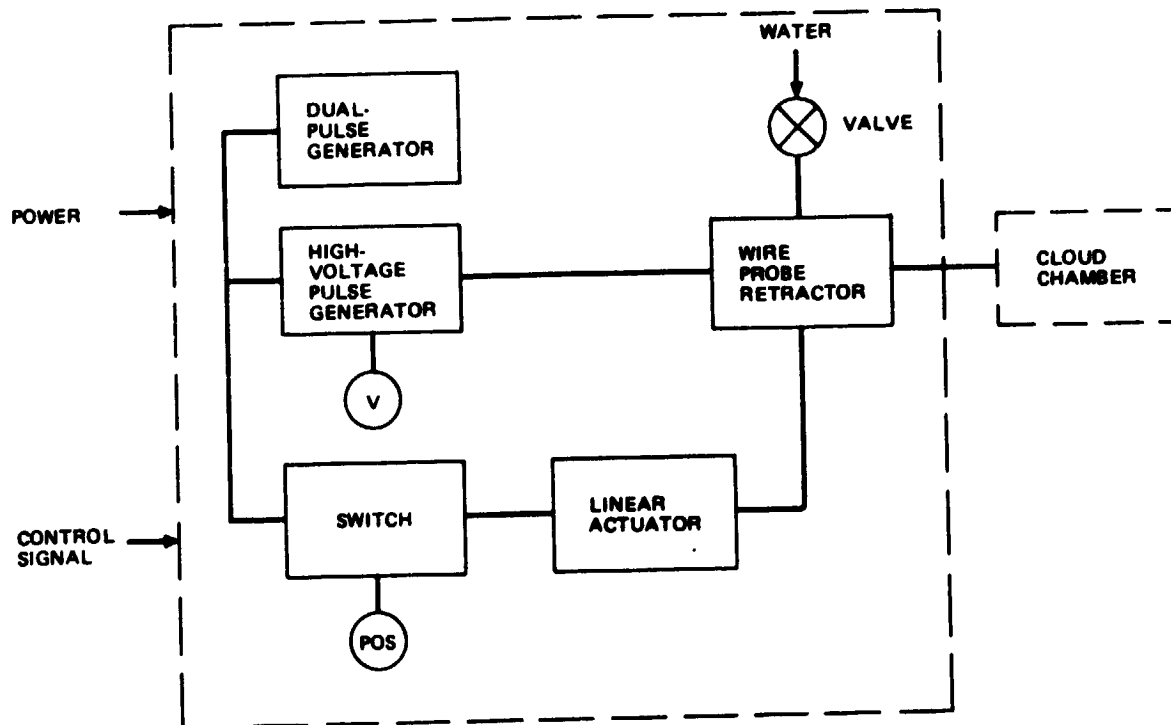
Figure 5-4. Wire Probe Retractor Generator

WATER

POWER

HIGH-
VOLTAGE
PULSE
GENERATOR

VALVE

SWITCH

SOLENOID
DRIVER

WATER
DROP
IMPELLER

CLOUD
CHAMBER

CONTROL
SIGNALS

POS
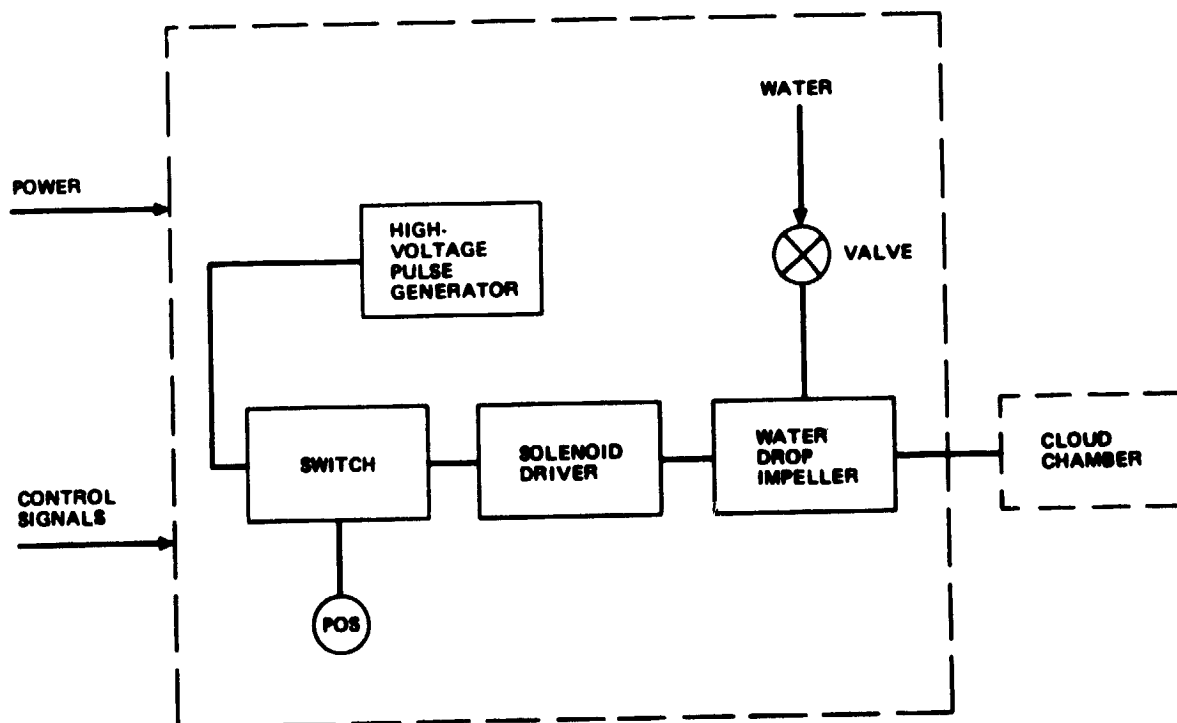
Figure 5-5. Water Drop Impeller Generator

from the droplets, uniform particles of the nonvolatile solute are obtained. Figure 5-6 is a block diagram of the assembly.

5.2.4 Evaporation/Condensation Aerosol Generator

The heat exchange evaporation-condensation technique has been extensively studied. It is perhaps one of the more reliable methods of aerosol generation. By proper control of experimental variables, one can generate 30 $\overset{\bullet}{A}$ to 3 micron (diameter) aerosols of NaCl and AgCl. This is accomplished by a gas of known flow rate entering a furnace, which for generating the NaCl and AgCl, operates at temperatures near 900° C. A boat containing the aerosol material is located in the center of the furnace. The contents of this boat provide a source of vapor for aerosol formation. Air, nitrogen, helium, or any other nonreactive gas is passed through this furnace and mixed with the vapor of the aerosol material. This mixture, upon leaving the first furnace, is quenched to room temperature thus forcing the vapor to condense into the primary aerosol. The primary aerosol then passes through a second furnace operating at least 10° C higher than the first. Here the aerosol evaporates and, upon leaving the second furnace, recondenses to form the secondary aerosol. Use of the second furnace results in a slightly more monodispersed aerosol. Figure 5-7 is a block diagram of the assembly.

5.2.5 Spray Atomization Nuclei Generator

Mechanical atomization of liquids in atomizers, nozzles, etc., which is made use of in many fields of industry, gives as a rule very polydispersed mists. The mechanism of atomization is as follows: under the action of hydraulic pressure, a centrifugal or an aerodynamic force, the liquid is drawn into narrow ligaments or films, which subsequently disintegrate into droplets under the action of the surface tension. The thinner the liquid ligament, the smaller are the droplets formed. The hydrosphere nebulizer prepares a film of water for aerosolization by flowing it over a hollow sphere. A small orifice in the sphere expels gas at supersonic velocity. This high-velocity gas ruptures the thin film of water and produces continual dispersion of fine liquid particles. These particles are reduced to an ultrafine aerosol as they are forcefully propelled against an impactor. This aerosol passes through a
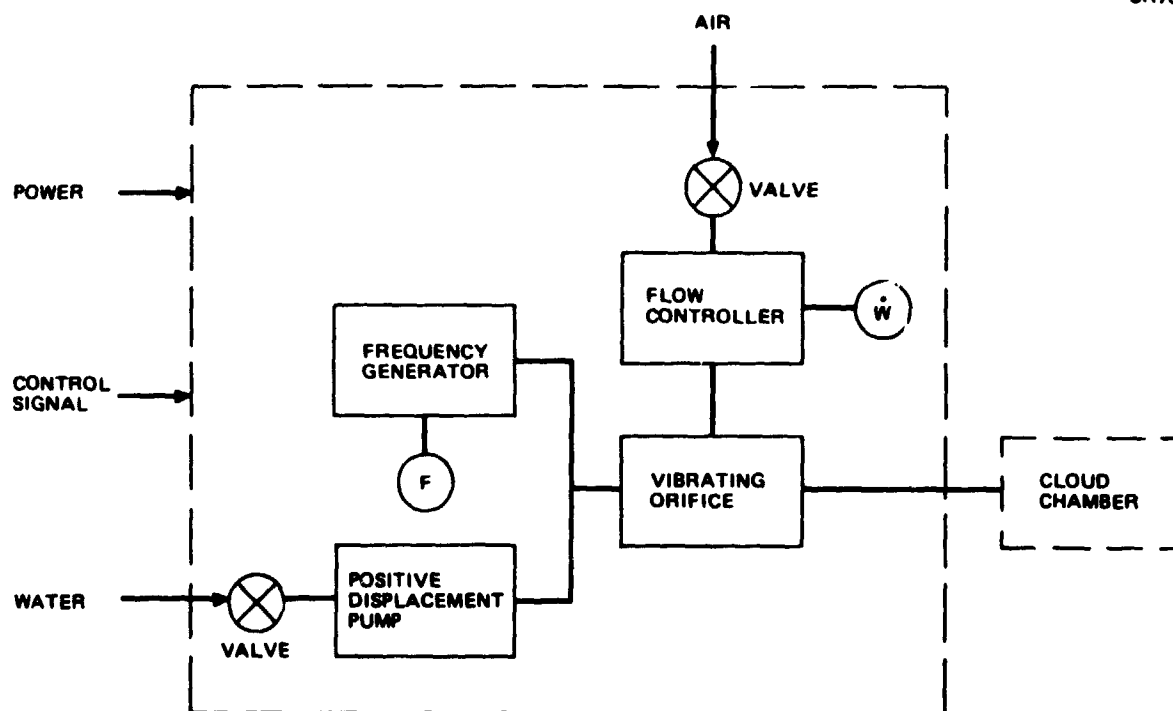
Figure 5-6. Vibrating Orifice Generator
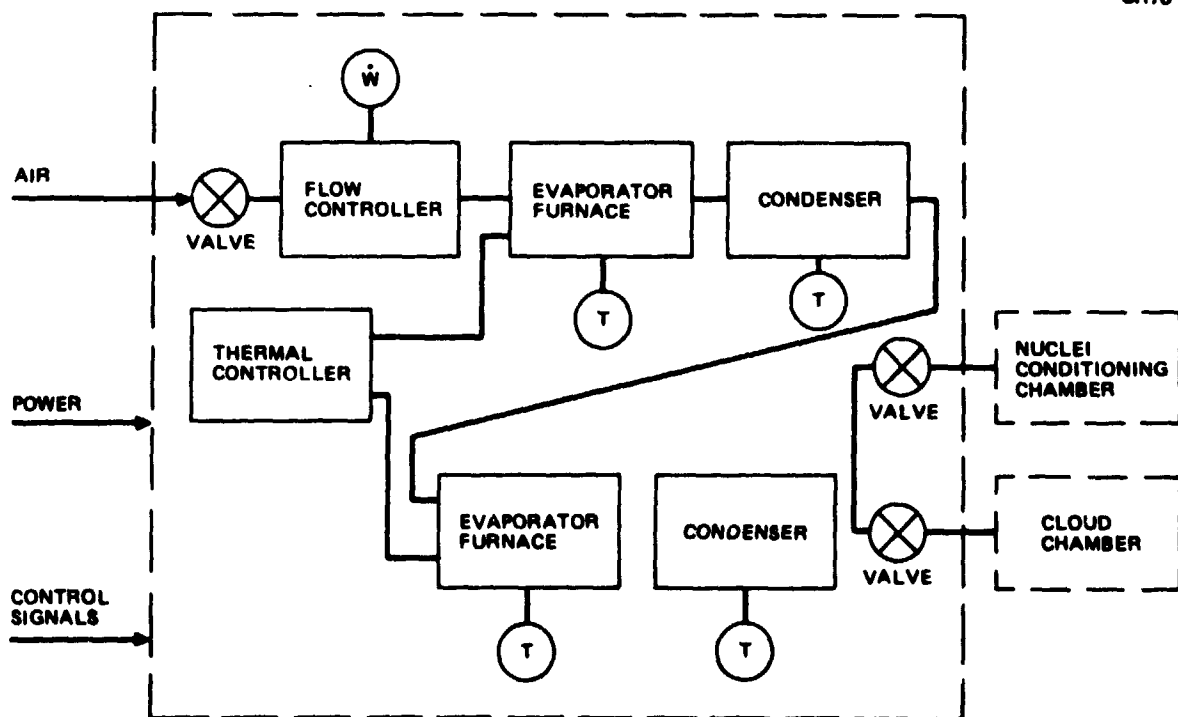
Figure 5-7. Evaporator Condenser Generator

drift tube where dry gas is added to promote evaporation of the water and produce the dry aerosol. Figure 5-8 is a block diagram of the assembly.

5.2.6 Powder Dispersion Nuclei Generator

The dispersion of a powder after placement in the aerosol generation box can be accomplished through aeration of the sample from a high-velocity nitrogen stream. A device similar to that used by Perkins (1952) will be considered for disseminating the finely divided powder into the conditioning chamber. In this apparatus, the powder is compacted into a rod-shaped pellet which is eroded by a high-velocity jet, generating an aerosol that is largely composed of single particles. The generator itself consists of hypodermic needles which are directed toward the top of the pellet tangentially and at an inclination of 45 degrees. Compressed air supplied to the nozzles produces a high-velocity vortex which erodes particles away from the cylinder and into the airstream. Figure 5-9 is a block diagram of the assembly.

5.2.7 Particle Injector and Size Conditioner

Supercooled water droplets and single ice crystals are required in several experiment classes. The interaction of ice with supercooled water and ice with ice in such experiments as collision-induced freezing and riming and aggregation will be investigated. In these experiments droplet size, impact energy, temperature, pressure and relative humidity must be controlled precisely. To accomplish this a particle injector and size conditioner is required. This generator will work on the same principle as the static diffusion thermal chambers where the relative humidity and temperature are controlled by the two horizontal wet surfaces spaced a few centimeters apart. These surfaces could either be ice or water depending on type of droplet required.

A water droplet is injected into the generator by one of the liquid water drop generators. If ice is required, the droplet will be nucleated. An acoustical assembly will provide motion and orientation control of the droplets/ice crystals within the generator while they are being conditioned. Positioning is required because ice crystals could take several hours at the low supersaturation rates to grow to the size required. Two viewports are required for observation during growth and for precise measurements of the droplets/
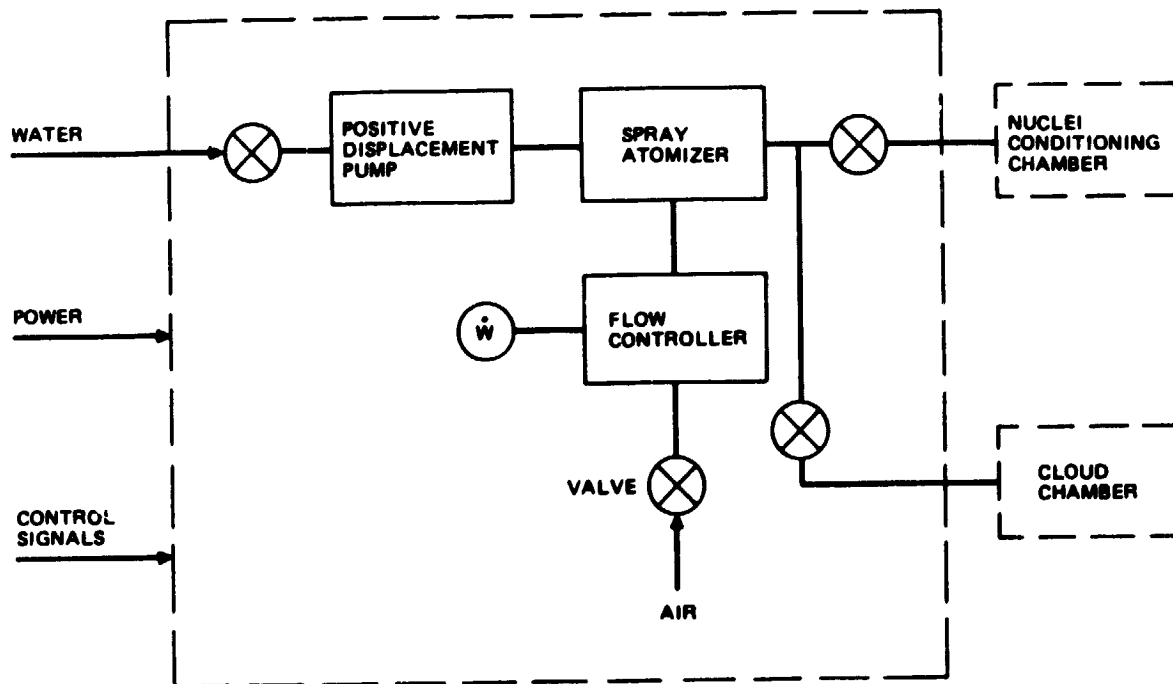
Figure 5-8. Spray Atomizer Generator
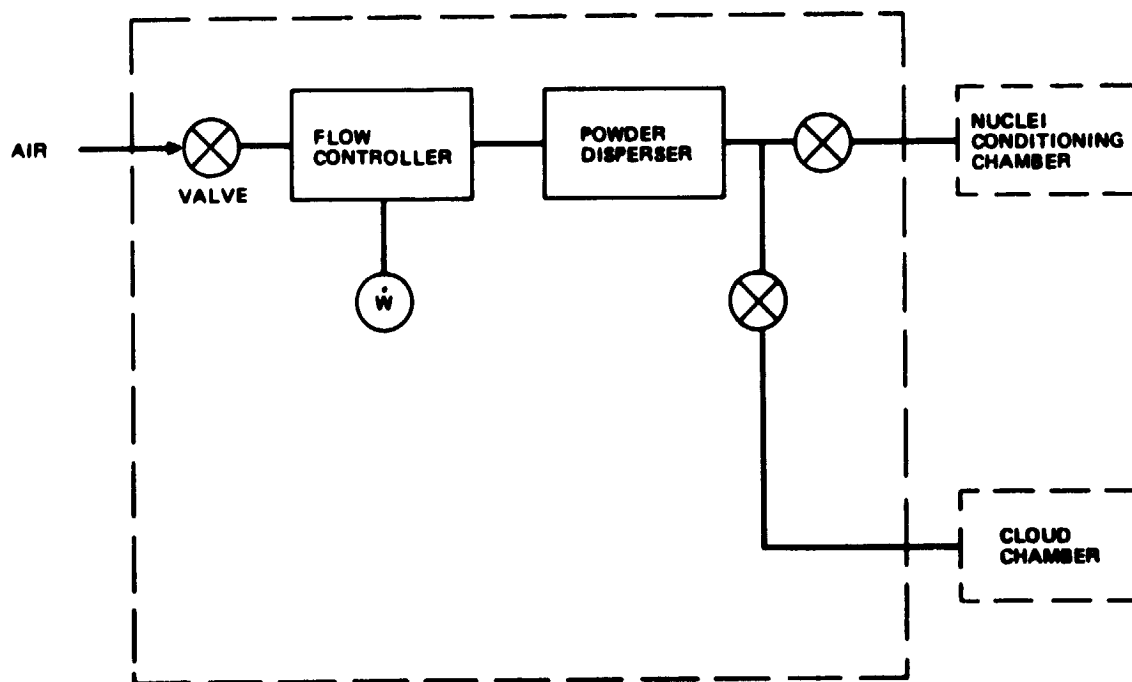
Figure 5-9. Powder Dispersion Generator

ice crystals. The generator could also be used for storing ice crystals for long periods. By means of an acoustical and/or optical positioning device, the droplet/ice crystal can be propelled into the experiment chamber. This will be an item for development. A block diagram of the assembly is shown in Figure 5-10.

5.3 DATA MANAGEMENT

The data management subsystem (DMS) consists of that equipment allowing development and operation of the CPL with a minimum of special-purpose simulation or support and that portion provided by the laboratory. This division is illustrated in the DMS block diagram (Figure 5-11) by the dashed line. The interface adapter provides interface compatibility between the two system elements with the exception of the video components which interface directly with breakout boxes provided by Spacelab. Operation of the Spacelab functions during development would be performed by standard laboratory equipment.
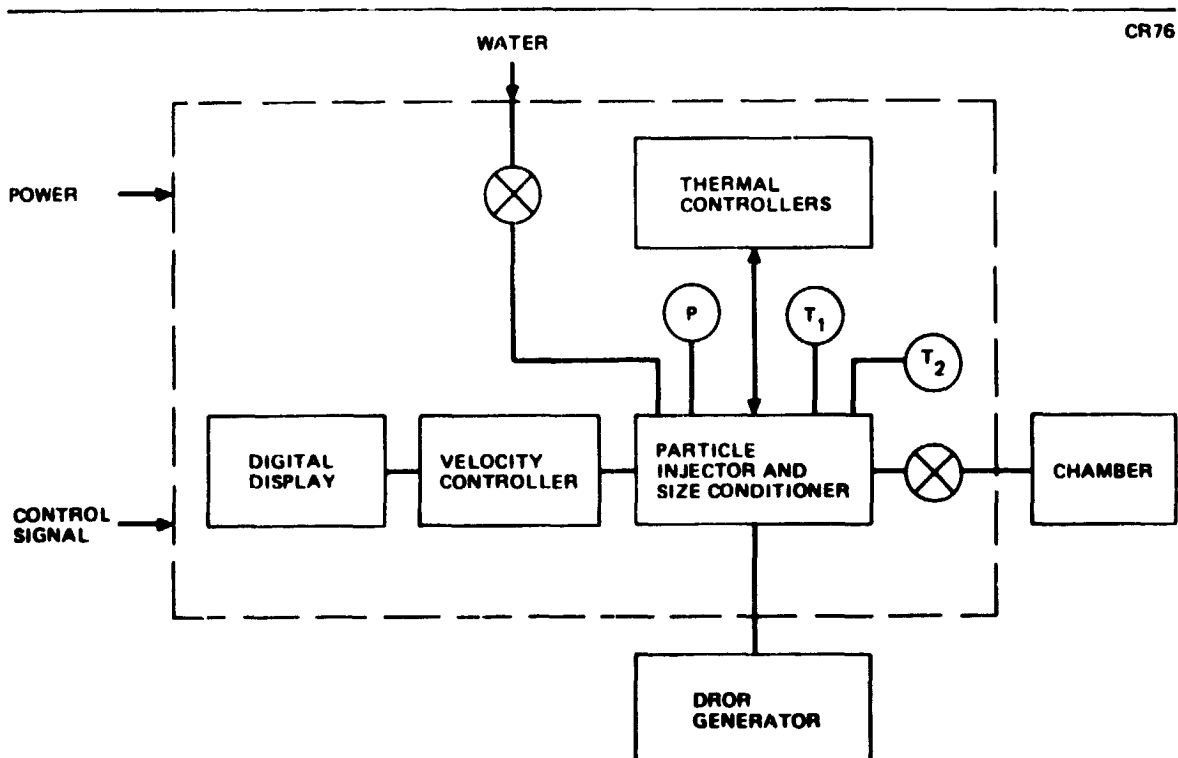
Figure 5-10. Particle Injector and Size Conditioner
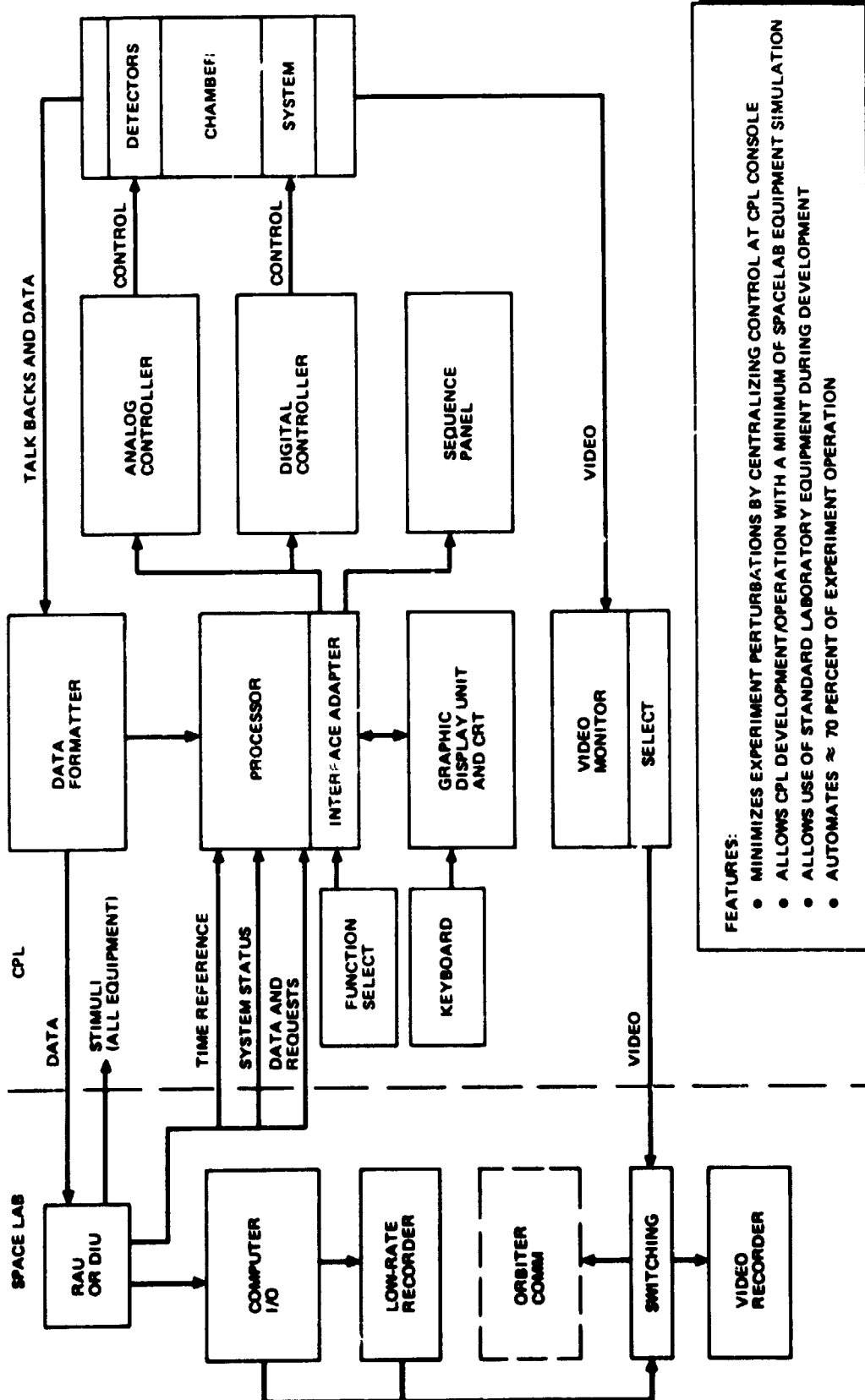
Figure 5-11. Data Management Block Diagram

The processor performs all valve sequencing operations with the exception of those few performed manually. Control would be exercised interactively with the operator by incorporating "Requests for Data" or "Halt" points within the programs. These would allow an opportunity to modify the program data base or select alternate continuation sequences depending upon each experiment's particular needs. They would also provide a "hold" period to allow the operator time to consult procedures or the progress of the experiment to that point. Operator control would be exercised via the keyboard and function select keys. Information would be displayed on the graphics display unit and by the sequence panel which would contain a diagram of the system and lights indicating the status of the experiment in progress. The processor would output commands via the interface adapter to either the analog or digital controller. The controllers would provide either analog or digital (discrete) signals to the appropriate valves, detectors, or CPL control devices.

Talkbacks from these units would be conditioned to have the proper signal characteristics for data acquisition by the formatter. This unit would sample the signals in a preprogrammed sequence, provide the appropriate talkbacks to the processor, and route all data to the remote acquisition unit (RAU) in serial digital form. The data would periodically be accessed by the Spacelab computer and routed to either the low-rate recorder or brought into memory. The latter procedure would be performed if a checkout sequence was being performed. The computer also is the repository for all experiment procedures and display formats and provides the commands controlling the status of the CPL processor entered via the keyboard.

The DMS is a permanent part of the CPL, flying on all missions. It consists of the assemblies and subassemblies shown in Figure 5-12. These assemblies, in turn, contain the components and subassemblies shown in column 2 of Table 5-5 which also contains a summary of their characteristics. In some instances where it is intended to use components developed for Spacelab (to eliminate nonrecurring costs), assumptions have been made due to the limited amount of published data (see Table 5-6). Specifications for this equipment should be available following the laboratory "Preliminary Requirements Review" which is scheduled to occur February 1975.
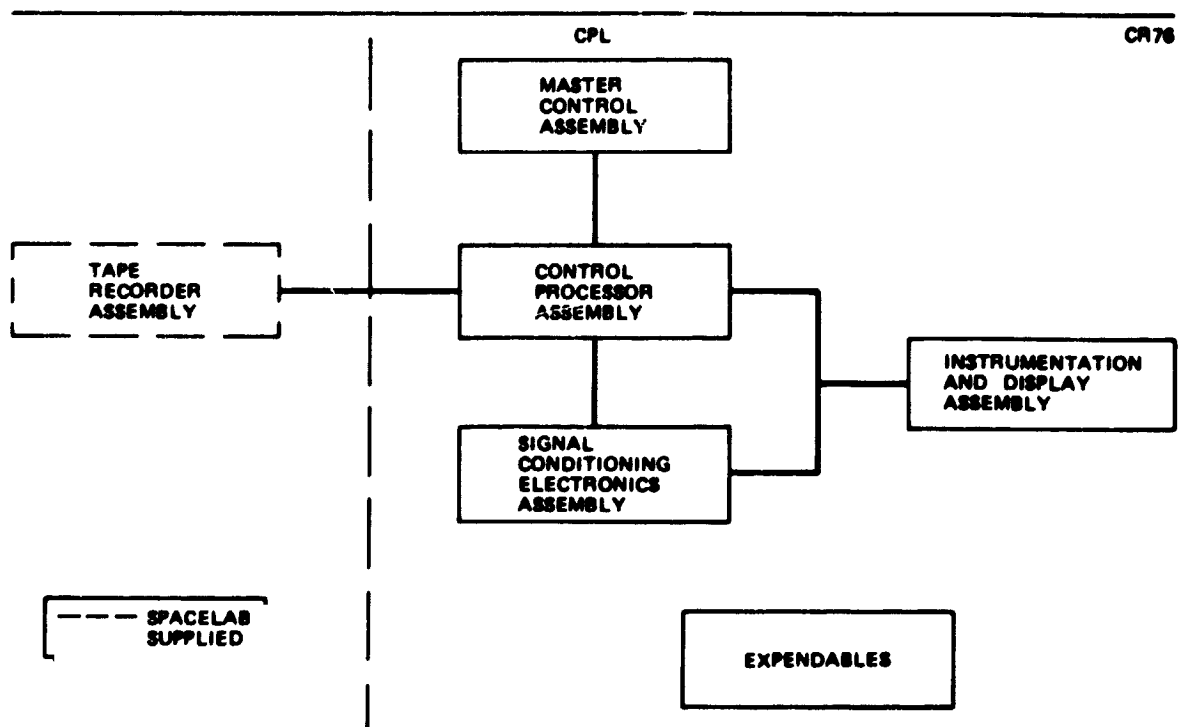
Figure 5-12. Spacelab DMS Equipment Diagram

5.3.1 Control Processor Assembly

The assembly includes a control processor, an interface adapter, shown in Figure 5-13, and two control units. The control processor contains an integral 4K, 16-bit word plat d wire memory, four program registers, four index registers, and eight accumulators. Typical execution times are: add, 2.4 µsec; multiply, 10.4 µsec; and divide, 30.4 µsec. It also contains an I/O consisting of 16-bit parallel bus input and output lines, a serial input/output line, and an external clock input. The interface adapter shown in Figure 5-13 consists of multiplexing, addressing, and decoding circuitry using T^2L flatpacks. Connectors are provided for the control processor, controllers, RAU interface formatter, sequence display, function select switches and power (eight total). The control units consist of an analog and digital controller. See Figure 5-14 for block diagrams of these units. The analog controller contains digital address and bias decoding circuits which select and control the gain of analog amplifiers and drivers. One input, one output (20 drivers), and one power connector are provided. The digital controller contains digital address decoding circuits, 60 discrete 28-volt drive outputs, and 10 serial outputs. One input, one output, and one power connector are provided.

Table 5-5

DATA MANAGEMENT SUBSYSTEM CHARACTERISTICS

Assembly	Component or Subassembly	Weight (kg)	Volume (m^3)	Power Maximum Operating (watts)	Power Nominal Operating (watts)	% Usage Experiment Time	Average Power (watts)
Control Processor Assembly	Control Processor	5	0.002	10	10	100	10
	Interface Adapter	10	0.008	5	5	100	5
	Control Units	14	0.006	10	10	100	10
Master Control Assembly	Keyboard	4	0.012	10	10	100	10
	Discrete Controls	15	0.009	40	40	100	40
Signal Conditioning and Electronics Assembly	Signal Conditioning	10	0.005	12	12	100	12
	Formatter	5	0.001	11	11	100	11
	RAU	2	0.002	7	7	100	7
	Intercom	10	0.007	19	19	100	19
	Instrumentation	4	-	-	-		19
Instrumentation and Display Assembly	Video Monitor	16	0.040	60	60	80	48
	Graphics Display Unit	30	0.102	250	250	60	150
	Sequence Display Unit	12	0.008	40	40	100	40
	Time Display	3	0.003	30	30	100	30
	Cabling	30	-	-	-	100	-
Expendables	Tape-Video	30	0.100	-	-	100	-
	Tape-Digital	4	0.006	-	-	100	-
Totals for Experiment Classes		244	0.311	449	449	100	392

Table 5-6

SPACELAB DATA MANAGEMENT EQUIPMENT CHARACTERISTICS

CRT AND KEYBOARDS

- Three CRT's plus three keyboards in cross-strapping configuration
- Keyboards provide numerics, 6 alphabetical characters, clear call, enter keys message display before entry
- CRT's in three colors: 16 lines x 64 characters
- Symbol generator provides vectors, alphanumerics, symbols
- Two sizes for characters, solid or dashed lines, blinking
- Stroke writing on 15-inch screen

REMOTE ACQUISITION UNIT (RAU)

- Multiplexer-demultiplexer for data acquisition and command distribution
- 14 RAU's interfacing with two I/O units through data bus (three twisted shielded pairs, redundant bus)
- For each RAU: 64 analog in, 8 x 8 bit digital in 2 PCM lines out, 16 on-offs out
- Built-in buffer for high rate data (1 Mbit)
- Checkout by parity and test mode
- Message repeat in case of commands

RECORDING

- Two recorders (Odetics) for digital and analog buffer and dump (tapes are removable)
- 30 Mbps digital recorder. MTBF= 5,000 hr at error rate 10^{-6}, data capacity 3.6×10^{10} bits for 20-minute record
- Analog recorder provides two channels at 6 MHz MTBF = 8,000 hr.
  FM, 20 minutes recording per tape
- Recorders use existing space technology

CAUTION-WARNING

- Hardwired CW independent from computer
- Two panels and one electronic unit
- Level 1 alarms (crew abort), flashing lamp and modulated sound
- Level 2 alarms (require human action), lamps with identification and sound
- End-to-end test of all alarms
- Interface to intercom for headset and additional loudspeaker activation
- Sensors are dual and all logic is redundant
- Capability: Level 1 - 1 annunciato.; Level 2 - 10 annunciators

INTERCOMMUNICATION

- Two 2-way channels for normal intercom
- One 2-way channel for emergency intercom
- Point-to-point or conference communication
- One main station and four remote stations in laboratory, tunnel, PSS, loudspeakers and headsets
- Emergency intercom electronically independent
- Interface with caution-warning

TIME DISPLAY

- Display GMT and MET (mission elapsed time)
- Four event timers, capability of 100 hours, accuracy 1/10 seconds, time preselection by thumbwheels
- Delivers start and end signals to experiments
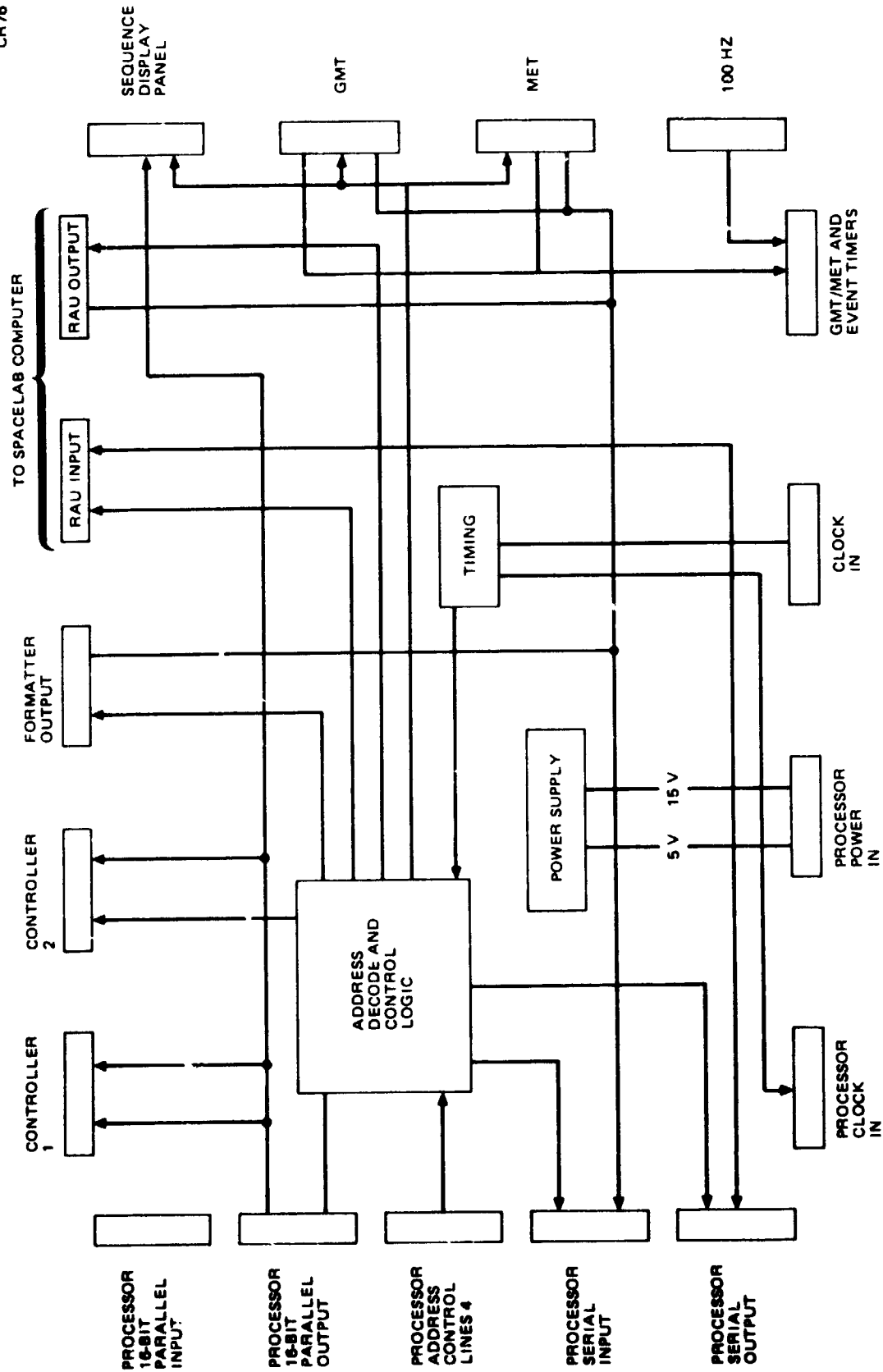
Figure 5-13. Interface Adapter

DIGITAL

INPUT REGISTER → ADDRESS DECODE, CONTROL LOGIC → GATES → RELAY/ SOLENOID DRIVERS → TO VALVES AND SOLENOIDS

ADDRESS DECODE, CONTROL LOGIC → COUNTERS → COMPARATOR → GATES

CLOCK

DC   AC

ANALOG

INPUT REGISTER → ADDRESS DECODE, CONTROL LOGIC → GATES → AMPLIFIERS → TO DEVICES

POWER SUPPLY → GATES

CLOCK
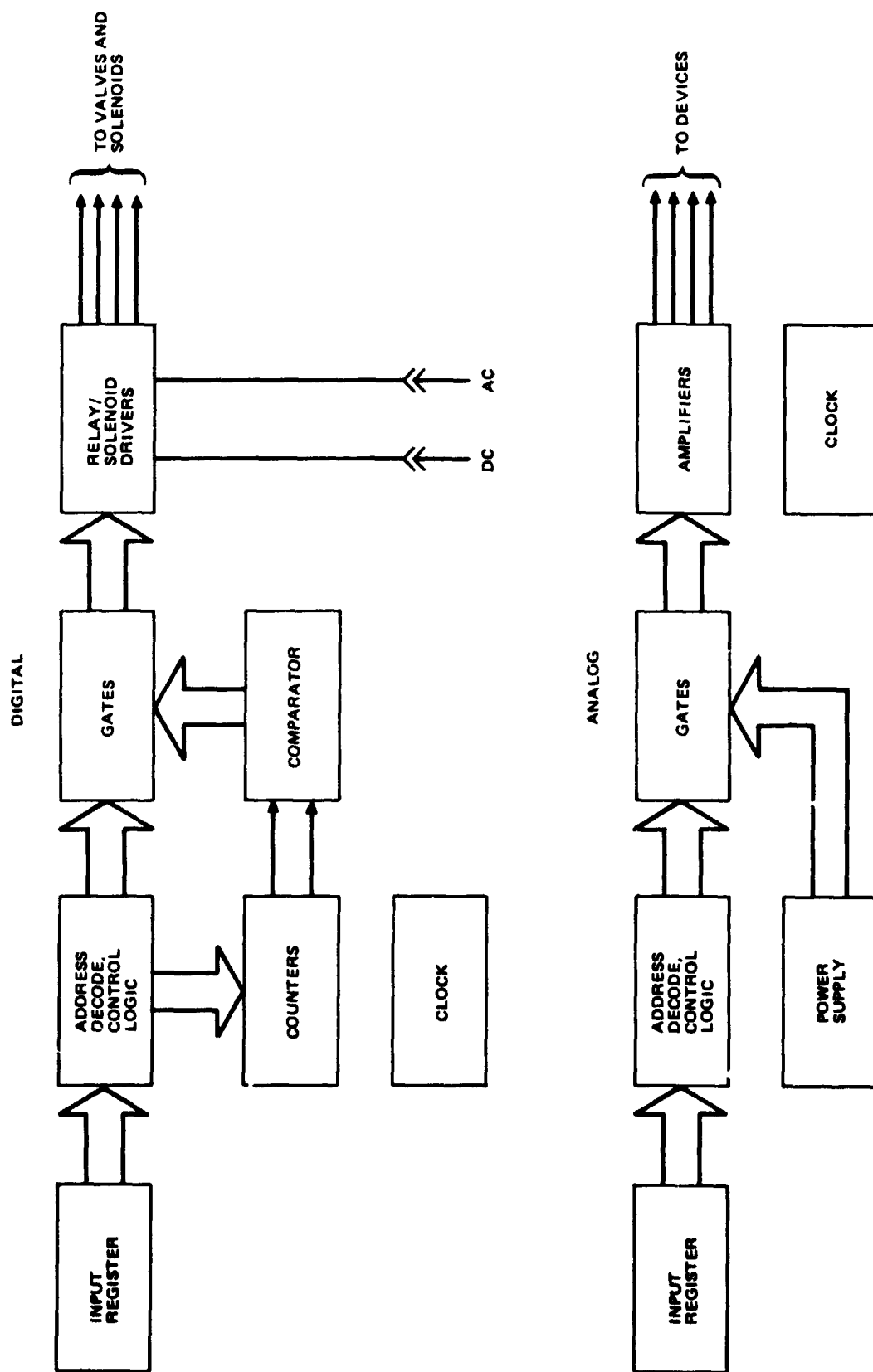
Figure 5-14. Controllers

5.3.2 Tape Recorder Assembly

The tape recorder assembly is assumed to include a seven-track, variable-speed, low-rate digital recorder. Although not available in the present baseline, it is carried as an option which must be eventually provided if the system is to support the experiment program. The assembly also includes an analog (video) recorder whose characteristics are as described in Table 5-6.

5.3.3 Master Control Assembly

The master control assembly consists of a keyboard and discrete switch panels. The keyboard will be identical to the units provided for Spacelab consoles and described in Table 5-6. Switch panels will consist of pushbutton, toggle, and rotary switches for equipment operation and control.

5.3.4 Signal Conditioning Electronics Assembly

The electronics assembly includes the signal conditioning unit, the formatter, and the RAU. It also includes the intercommunication although the latter is included in this assembly only as a matter of convenience. The signal conditioning unit contains analog and digital circuits for bridge circuit completion, counting, amplification frequency to dc conversion, etc. on individual circuit cards installed in a single enclosure. The circuits will be designed to provide compatible interfaces between circuit and transducer outputs and data acquisition inputs. All circuits will be capable of accepting calibration commands and producing a standard output 80 percent of full scale. Multiple connectors are required.

The formatter will time multiplex approximately 200 analog and digital inputs at prescribed sampling rates and convert them into 10-bit words output as a continuous digital bit stream. Hardware or firmware programming is adequate, i.e., a simple device is indicated. Two outputs are to be provided, one interfacing with an RAU and one with the CPL processor.

The RAU performs much the same functions as the formatter, the difference being that input addressing is controlled by the Spacelab computer rather than internal fixed programming. The units use an 8 bit rather than 10 bit word and the characteristics of the serial data inputs are undefined.

The remote intercom unit is a standard Spacelab equipment item containing receive and transmit amplifiers, volume controls for speaker, headsets and microphones, voice and channel select. Tacks for two headsets and microphones are provided.

5.3.5 Instrumentation and Display Assemblies
Instrumentation would consist of temperature transducers (primarily thermistors), voltage/current sensors, and video cameras. Circuit outputs would also be provided for frequency measurements and digital register readouts. Display assemblies consist of graphic display units, sequence panels, and time readouts.

The video camera is a standard unit 525-line raster on a 1-inch tube with a 4.0-MHz bandwidth. The camera with a zoom lens sees through a beam splitter in one of the illumination modules which in turn is attached to the viewport to one side of the observational viewport. With a wider angle lens at this position, the unit provides the astronaut with a view of the chamber much greater than that provided by his microscope. Using the monitor screen, he can observe droplets introduced in the chamber and see the overall trajectory as they are propelled. Since the camera's video output can be recorded on a video tape recorder, the astronaut can playback scenes of droplet trajectories on the monitor at will. The camera and monitor give him another eye and viewing position to observe the experiment.

The graphics display unit is a Spacelab-developed unit consisting of a 15-inch diagonal color CRT together with a chassis providing horizontal and vertical deflection amplification, D to A converters, and a digital decoder and controller. A separate unit would provide character and line generation, refresh memory and buffers for interfacing the keyboard, and computer I/O.

The sequence panel contains an input register, diode-decoding matrix lamp drivers, and approximately 40 incandescent lamps which indicate the status of the CPL system and the progress of a particular experiment. The lamps are inserted in a diagram of the CPL. A converter provides the 5-vdc lamp supply.

The time display is a Spacelab-developed unit which accepts the IRIG code provided by the orbiter and converts it to binary-coded decimal form for driving an electro-luminescent time display. Either GMT or MET can be selected via switch. Two event items are also provided with time to go and elapsed time set by thumbwheel switches. The units count time from 0.1 second to 100 hours.

5.3.6 Expendables

Data management expendables include three digital and ten video tapes. The initial digital tape allocation was based upon recording for 10 hours per day, 6 days a week at a 1-kbps rate which produces 2.6×10^7 data bits, well within the capacity of a single 10-1/2-inch reel. Because of concern about the tape recording speed available, an alternate method of calculation was employed based upon a tape speed of 3-3/4 ips and 4,800 feet of seven-track tape permitting 30 hours of recording and requiring two tapes per mission plus one spare. The video tape allocation assumes 20 minutes of recording per reel based upon Spacelab data with the video camera operating in a burst mode rather than continuously. Although record time per day will probably exceed 2 hours, the ability to erase and reuse the tape after transmission to the ground via the TDRS should provide sufficient operation time with the indicated quantity of tape.

5.4 PARTICLE DETECTOR AND CHARACTERIZER

Several types of detectors will be required in the proposed experiments. These range from particle size analyzers to nuclei mass monitors. Nuclei are either condensation centers for droplet formation or solidification centers for ice crystal formation. Particles are either water droplets or ice crystals which have grown from nuclei to larger sizes. In order to understand the effects of nuclei in causing condensation, one must know both the characteristics of the nuclei and the resulting particles under known environmental conditions. Thus the nuclei measurement devices will provide information about the initial aerosol distribution while the optical particle counter and cameras will provide information during and after an experiment.

Relative humidity measurements will be required to be taken of the gas samples before they enter the chamber as well as during the experiment time in the chambers. These detectors are of fundamental importance to the total experiment program. These techniques must be adapted for operation in a low-gravity condition and functionally optimized for the specific experiment requirements.

Table 5-7 identifies and classifies the recommended major components of the particle detector and characterizer subsystem to be developed for the CPL.

Table 5-8 is a summary of equipment required by experiment class. Not all equipment indicated by class will necessarily fly on every mission. This subsystem includes the following assemblies:

A.   Optical particle counter

B.   Pulse height analyzer

C.   Condensation nucleus counter

D.   Microporous filter

E.   Quartz Crystal mass monitor

F.   Cascade impactor

G.   Electrical size analyzer

H.   Scatterometer

I.   Liquid water content meter

J.   Droplet size distribution meter

K.   Optical thermoelectric dew point hygrometer

L.   Electrical dew point hygrometer

Weight, power, and volume is given by assembly on Table 5-9 and by experiment class on Table 5-10.

5.4.1   Optical Particle Counters

Optical particle counters are precise scientific instruments which measure the size (in microns) and concentration (in particles per cubic foot) of particulates suspended in air. The basis for all light-scattering instruments is the Mie theory which defines the scattering from an optically isotropic sphere as a function of the ratio of the sphere size to the wavelength of illumination, of the refractive index of the sphere, and the angle between the incident light beam and the observer. Major limitations to this method are the criticality

Table 5-7

RECOMMENDED PARTICLE DETECTORS
AND CHARACTERIZERS

Component	Source/Specification	Size Range	Measures	Equipment Type	Classification	Status	Complexity	Remarks
Optical Particle Counter	(1) Royco Model 225 (2) Climet	0.3 to 10 μm	Particle size and numbers	Electrical/ Optical	Commercial	Current/ modification required	Average	Measures polydispersed particles
Pulse Height Analyzer	Nuclear Data Inc.	---	Pulse height	Electrical	Commercial	Current/ modification required	Average	Used with the optical particle counter
Condensation Nucleus Counter	GE (CNC-2)	0.0025 μm and larger	Concentration	Electrical/ Mechanical	Commercial	Current/ modification required	Average	Photographs taken and particles counted
Micro- porous Filter	(1) Nuclepore (2) Millipore	0.01 and larger	Total numbers	Mechanical	Commercial	Current/ modification required	Low	Not real time analysis
Quartz Crystal Mass Monitor	(1) Thermo Systems (2) Celesco	0.01 to 10 μm	Total mass	Electrical/ Mechanical	Commercial	Current/ modification required	Low	(2) Space qualified
Cascade Impactor	(1) BGI Inc. (2) Goetz (Centrifugal)	0.1 to 100 μm	Size Distribution	Mechanical	(1) Commercial (2) Special	(1) Current/ modification required (2) Laboratory	(1) Low (2) Average	Not real time analysis
Electrical Size Analyzer	Thermo Systems	0.0032 to 1.0μm	Size range and concentration	Electrical	Special	Current/ modification required	Average	Range would need extended
Scatter- meter	MDAC	0.5μm and larger	Size distribution	Electrical/ Optical	Special	Laboratory model available. Modification required.	Average	Advance development item.
Liquid Meter Content Meter	UMR	0.5 μm and larger	Liquid water content	Electrical/ Optical	Special	Laboratory model available. Modification required	Average	Advance development item
Droplet Size Distribution Meter	MDAC	0.5 μm and larger	Size Distribution	Electrical/ Mechanical Optical	Special	Laboratory model available. Modification required	High	Advance development item
Optical Thermo- electric Dew Point Hygrometer	EG&G	0 to 100% RH	Relative Humidity	Electrical/ Optical	Commercial	Current/ Modification required	Low	Primary measurement. No calibration required.
Electrical Dew Point Hygrometer	Phys- Chemical Research Corp	0 to 100%	Relative	Electrical	Commercial	Current/ Modification required	Low	Accuracy ± 2-1/2%

Table 5-8

EQUIPMENT LIST BY EXPERIMENT CLASS

Experiment Class	Optical Particle Counter	Pulse Height Analyzer	Condensation Nucleus Counter	Microporous Filter	Quartz Crystal Mass Monitor	Cascade Impactor	Electrical Size Analyzer	Droplet Size Distribution Meter	Liquid Water Content Meter	Optical Thermo-Elec. Dew Point Hygrometer	Electrical Dew Point Hygrometer	Scatterometer
1. Condensation Nucleation	X	X	X	X	X	X	X	X	X	X		
2. Ice Nucleation				X	X	X	X	X	X	X		
3. Ice Multiplication				X	X	X	X	X	X	X		
4. Charge Separation										X	X	
5. Ice Crystal Growth Habits	X	X	X	X	X	X	X	X	X	X		
6. Scavenging			X							X		X
7. Riming and Aggregation				X	X	X	X			X		
8. Droplet-Ice Cloud Interactions										X	X	X
9. Homogeneous Nucleation			X					X	X	X	X	X
10. Collision-Induced Freezing										X		
11. Saturation Vapor Pressure										X		
12. Adiabatic Cloud Expansion	X	X	X	X	X	X	X	X	X	X	X	X
13. Ice Nuclei Memory	X	X	X	X	X	X	X	X	X	X	X	X
14. Terrestrial Expansion Chamber Evaluation	X		X	X	X	X	X	X	X	X		
15. Condensation Nuclei Memory		X		X	X	X	X			X	X	X
15. Nuclei Multiplication			X							X		
17. Drop Collision Breakup										X		
18. Coalescence Efficiencies										X		
19. Static Diffusion Chamber Evaluation	X	X		X	X	X	X			X	X	
20. Unventilated Droplet Diffusion Coefficients				X	X	X	X	X	X	X	X	X

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Table 5-9

PARTICLE DETECTORS AND CHARACTERIZERS SUBSYSTEM FEATURES BY ASSEMBLY

Assemblies	Weight (kg)	Volume (m³)	Power Maximum Operating (watts)	% Usage Experiment Time	Average Power (watts)
Optical Particle Counter	30.43	0.079	237	20	47.4
Pulse Height Analyzer	9.7	0.02	20	20	4.0
Condensation Nucleus Counter	22.76	0.037	104	5	5.2
Microporous Filter	7.63	0.025	12	20	2.4
Quartz Crystal Mass Monitor	25.83	0.038	215	10	21.5
Cascade Impactor	13.	0.034	12	20	2.4
Electrical Aerosol Size Analyzer	28.73	0.058	43	10	4.3
Scatterometer	9.07	0.017	150	20	30
Liquid Water Content Meter	5.87	0.017	53	20	10.6
Droplet Size Distribution Meter	10.72	0.035	158	40	63
Optical Thermoelectric Dew Point Hygrometer	14.9	0.087	118	10	11.8
Electric Dew Point Hygrometer	10.2	0.014	127	5	6.35

Table 5-10

PARTICLE DETECTORS AND CHARACTERIZERS SUBSYSTEM
FEATURES BY EXPERIMENT CLASS

Equipment/Class	Weight (kg)	Volume (m³)	Maximum Operating Power (watts)	Average Power (watts)
1	169.86	0.427	972	231
2	106.97	0.29	611	116
3	106.97	0.09	611	116
4	25.1	0.10	245	18
5	40.57	0.15	479	115
6	163.47	0.39	888	104
7	34.17	0.117	395	48
8	132.41	0.307	781	83
9	31.49	0.13	329	85
10	25.1	0.10	245	18
11	34.17	0.117	395	48
12	178.93	0.446	1,122	203
13	106.97	0.29	611	116
14	189.13	0.46	1,249	209
15	129.73	0.33	715	121
16	163.47	0.39	888	104
17	25.1	0.10	245	18
18	25.1	0.10	245	18
19	153.27	0.27	761	98
20	116.04	0.31	761	146
21	-			

of the sensing angle, color and density effects of the fluid medium, changes in
the reflective and refractive indices of the materials, the tendency of some
fluids to absorb certain wavelengths of visible light thus causing less energy
to be focused on the target particle. Also the light-scattering devices are
limited to 0.3 micron. Figure 5-15 gives a block schematic of the
assembly.
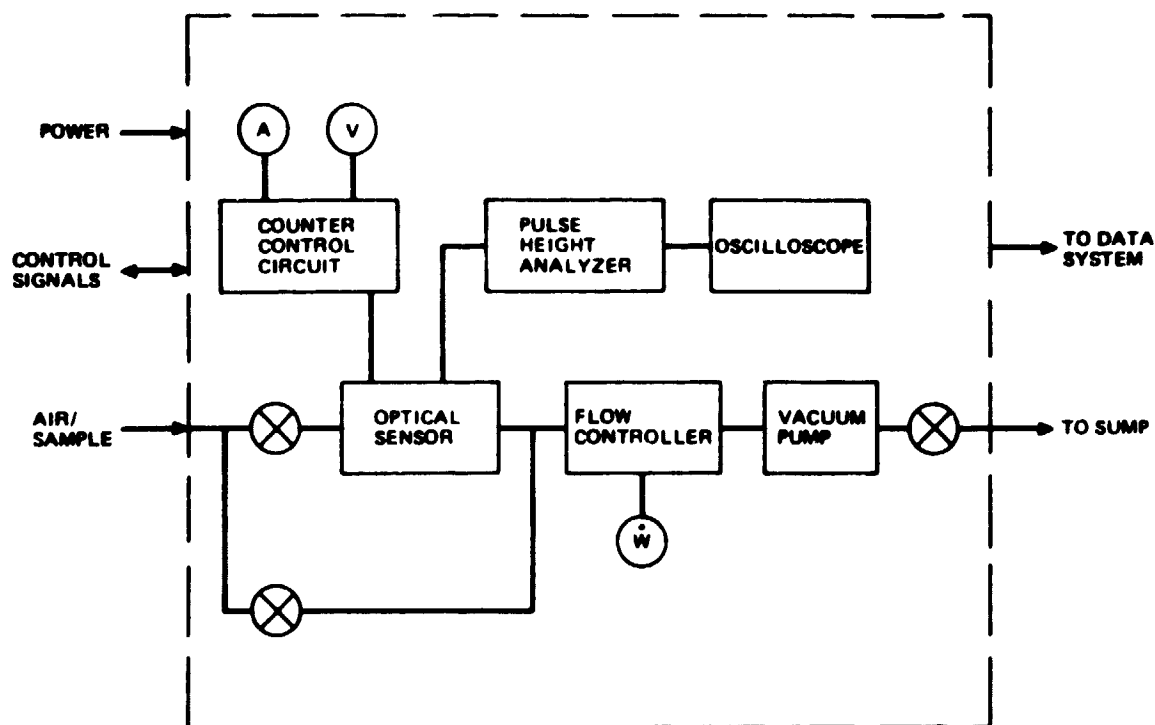
Figure 5-15. Optical Particle Counter

5.4.2 Pulse Height Analyzer

A pulse height analyzer is required to process the data from the optical
detector. This instrument can be used in a variety of experiments requiring
pulse height analysis and/or multichannel scaling. The module itself is
divided into three functional sections: the analog-to-digital converter section,
the data-handling section, and the memory section.

5.4.3 Condensation Nucleus Counter

The Aitken nucleus counters are used to measure the total aerosol concentra-
tion. These instruments are of the photoelectric type based on the Pollak 1957
counter and operate at the Aitken expansion of 1.2 to 1, in an attempt to
activate all aerosol particles as condensation nuclei. The walls are lined
with a wetted porous ceramic lining that provides the moisture supply to the
air sample. A light beam from the top of the chamber traverses the tube to
a photocell at the bottom. The instrument compares the ratio of light
scattered by the chamber before the expansion to the light scattered by the
fog in the chamber after the expansion, utilizing a dark field patch in the
light path, and a photomultiplier. Because the reference signal is the

light scattered by the fog-free chamber, this chamber and the lenses at the light source and photocell end must be kept clean for optimum performance. Attenuation of the photocell current has been calibrated in terms of the concentration of Aitken nuclei in the air sample. The counter is capable of measuring the Aitken nuclei concentration from less than 10 to 250,000 nuclei per milliliter. A block schematic of the assembly is shown in Figure 5-16.

5.4.4 Microporous Filters

The procedure consists mainly of passing a known volume of air through a microporous membrane filter, coating the suction side with a thin layer of viscous oil. The oil renders the filters transparent and seals the pores without wetting its upper surface. The filters are placed on a thermal conducting plate and placed in a diffusion chamber under controlled temperature and supersaturation. Ice crystals which grow on the surface of the filter are revealed by a light beam and may be counted. Samples on the filters will be stored and returned for final analysis. A block schematic of the assembly is shown in Figure 5-17.

5.4.5 Piezoelectric Quartz Crystal Mass Monitor

This is an instrument for automatically and continuously monitoring the mass concentration of airborne particles. The aerosol to be sampled is drawn into the electrostatic-precipitator chamber at a flow rate of 1 liter/minute. All of the particles in the air stream are deposited onto the surface of the sensor with a highly efficient electrostatic-precipitator collector. The sensor is a piezoelectric quartz crystal oscillating at its resonant frequency. It is driven by a solid-state oscillator circuit. The resonant frequency of the quartz crystal decreases linearly with the total mass of the particulate deposition, thereby automatically weighing the airborne particles. A second sensor - the reference quartz crystal - compensates for possible changes in ambient effects, such as temperature and gas composition. The time rate-of-change of the output frequency signal is directly proportional to the total particle mass concentration in the range of about 0.01 to 10 microns. A block schematic of the assembly is shown in Figure 5-18.
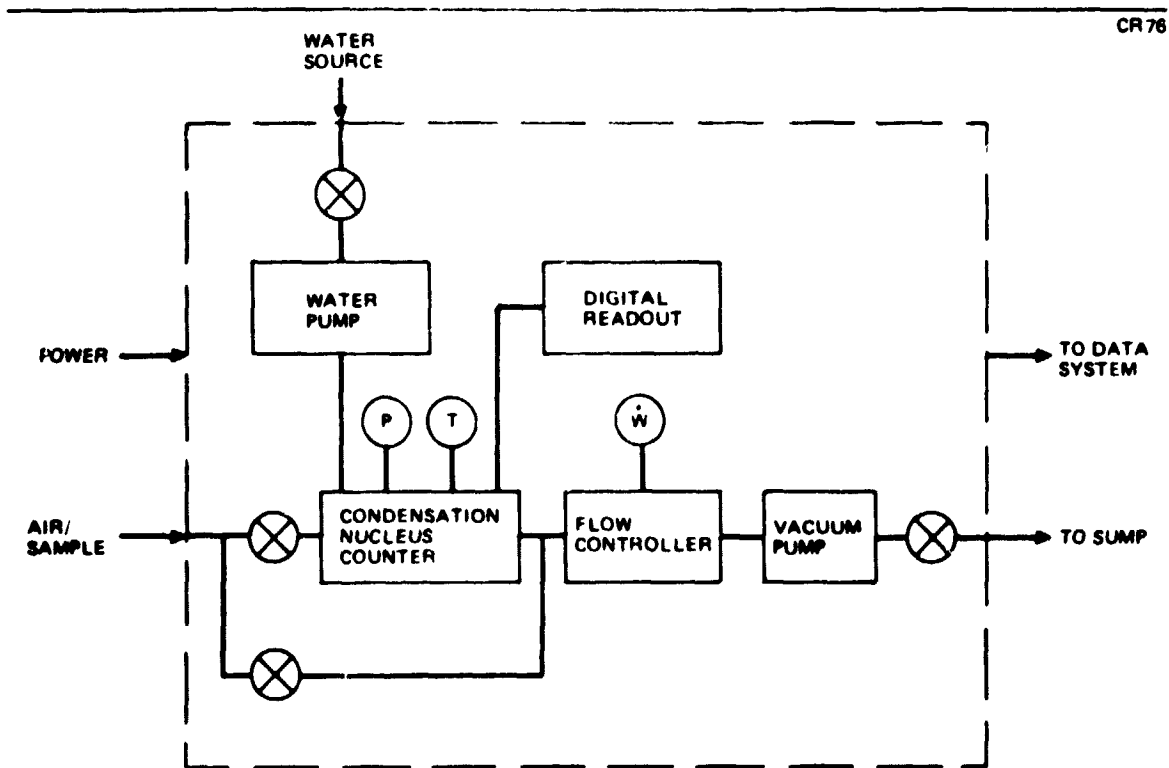
Figure 5-16. Condensation Nucleus Counter
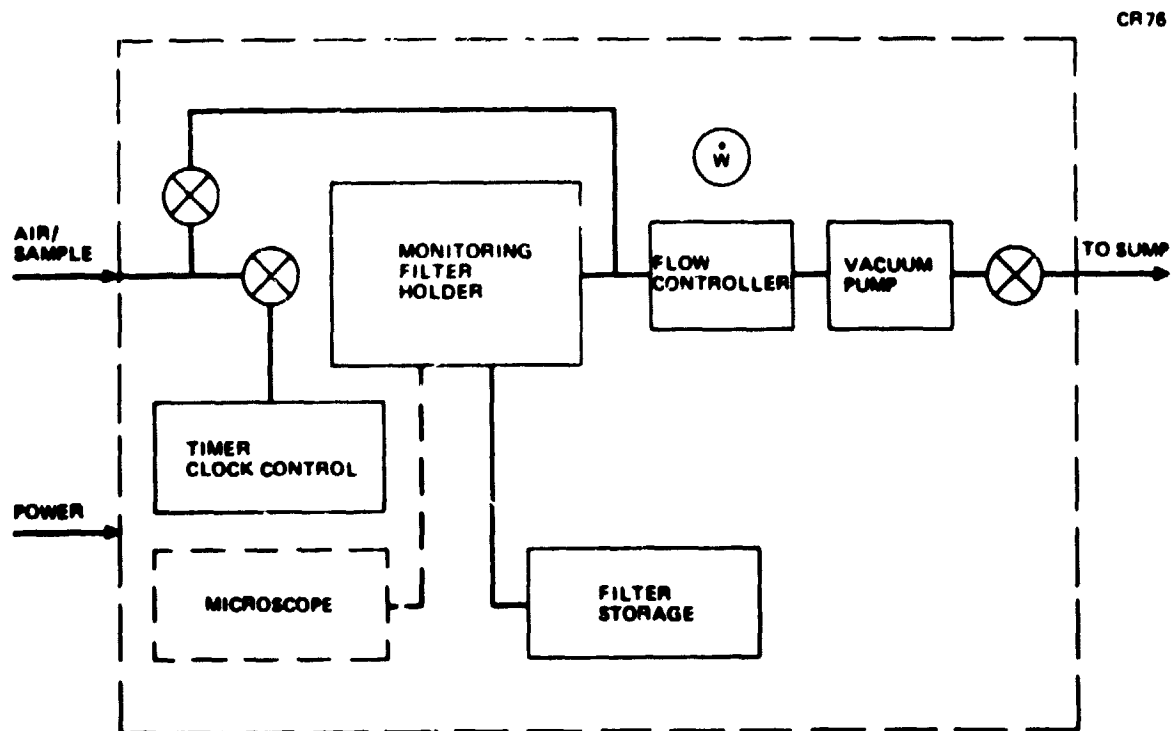
Figure 5-17. Microporous Filter Subsystem
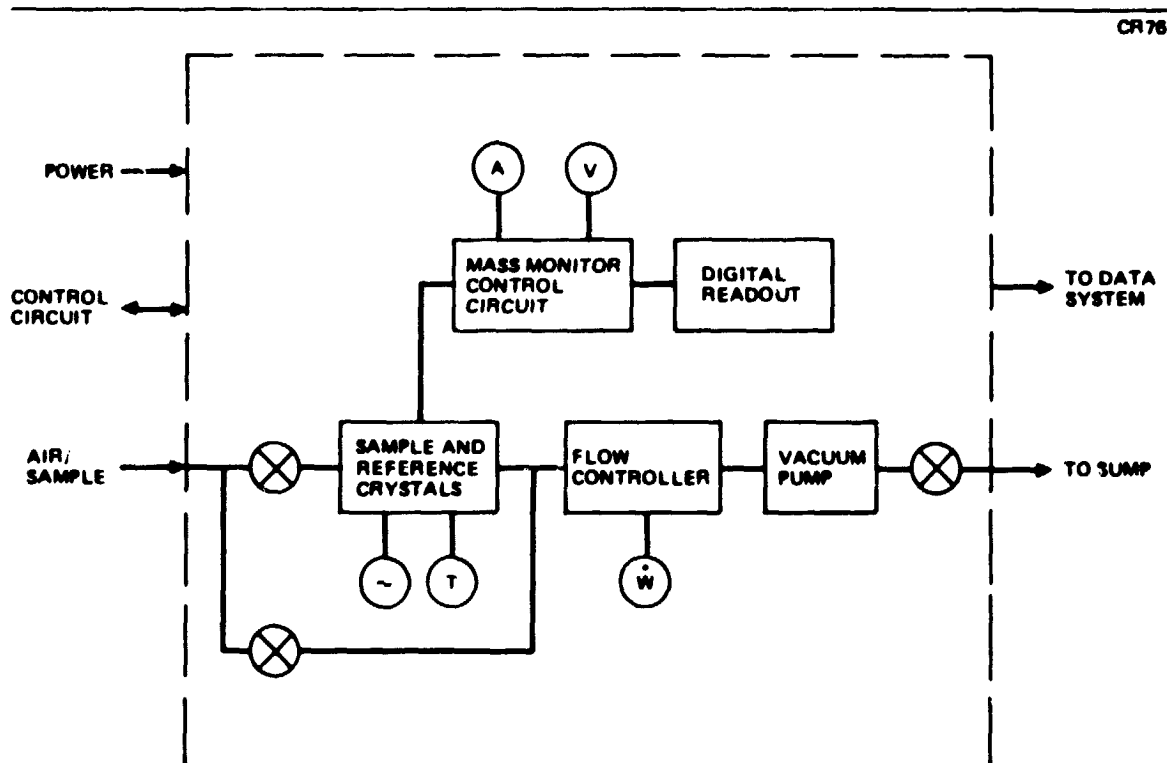
Figure 5-18. Piezoelectric Quartz Crystal Mass Monitor

5.4.6 Cascade Impactor

The cascade impactor operates on the principle that particles in a moving air stream will impact on a slide placed in their path provided that inertia of the particles is sufficient to overcome the drag of the air stream as it moves around the slide. The jet in each stage of the impactor is smaller than the one that preceded it. The velocity of the airstream and the dispersed particles increase as the aerosol advances through the impactor. Smaller particles eventually acquire sufficient momentum to impact on a slide with the result that particle size classification is achieved.

It is possible to find the size distribution by just microscopically enumerating the particles on the slides in each stage of the impactor. The range of the instrument is determined by the number of stages used in the cascade which can measure particles from 0.1 to 100 μm. A block schematic of the assembly is shown in Figure 5-19.

5.4.7 Electrical Aerosol Size Analyzer

Counting and sizing with the electrical aerosol size analyzer is based on a process of charging the particles with a unipolar charge and then measuring the mobility distribution of the charged particles.
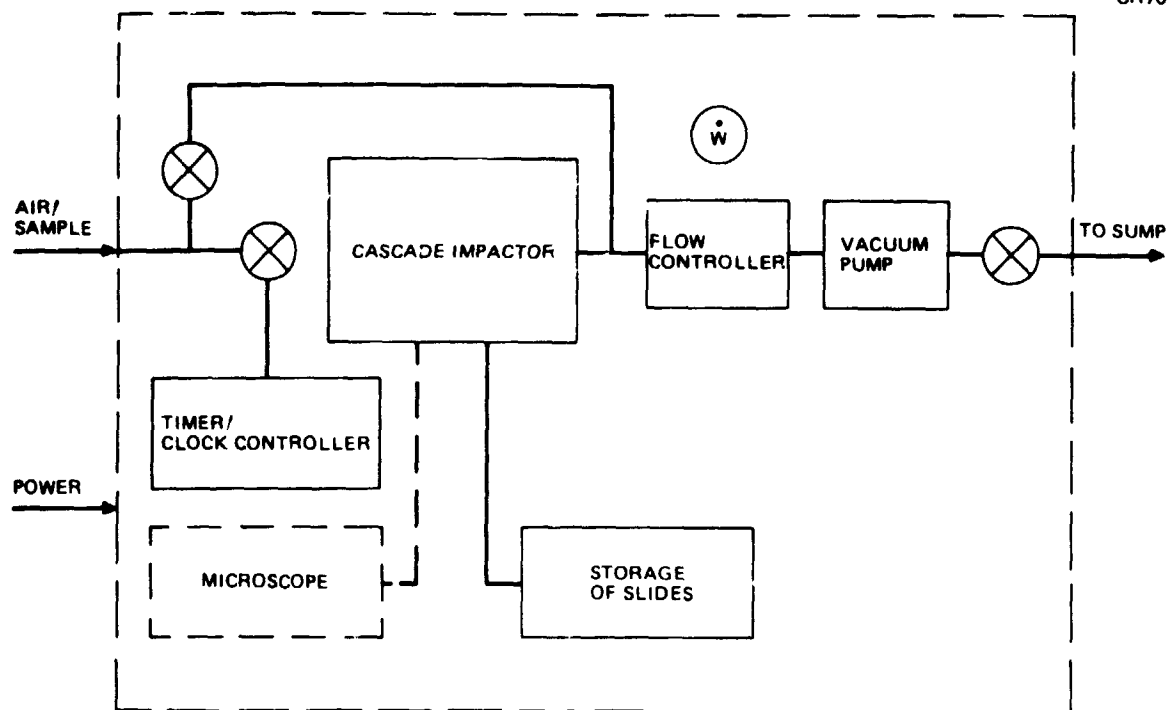
Figure 5-19. Cascade Impactor

As a vacuum pump draws the aerosol through the analyzer, a corona generated by a high-volt ;e wire within the charging section gives the sample a positive electrical charge.

The charged aerosol flows concentrically from the charger to the analyzing tube section which is an annular cylinder of aerosol surrounding a core of clean air. A metal rod, to which a variable, negative voltage can be applied, passes axially through the center of the analyzer tube. Particles smaller than a certain size (with high electrical mobility) are drawn to the collecting rod when the voltage corresponding to that size is on the rod. Larger particles pass through the analyzer tube and are collected by the current collecting filter. The electrical charges on these particles drain off through an electrometer, giving a measure of current. A block schematic of the assembly is shown in Figure 5-20.

5.4.8 Scatterometer (Optical Detector)

The scatterometer is an instrument to measure the angular scattering profiles of various particles of ice and water as they undergo or have undergone a
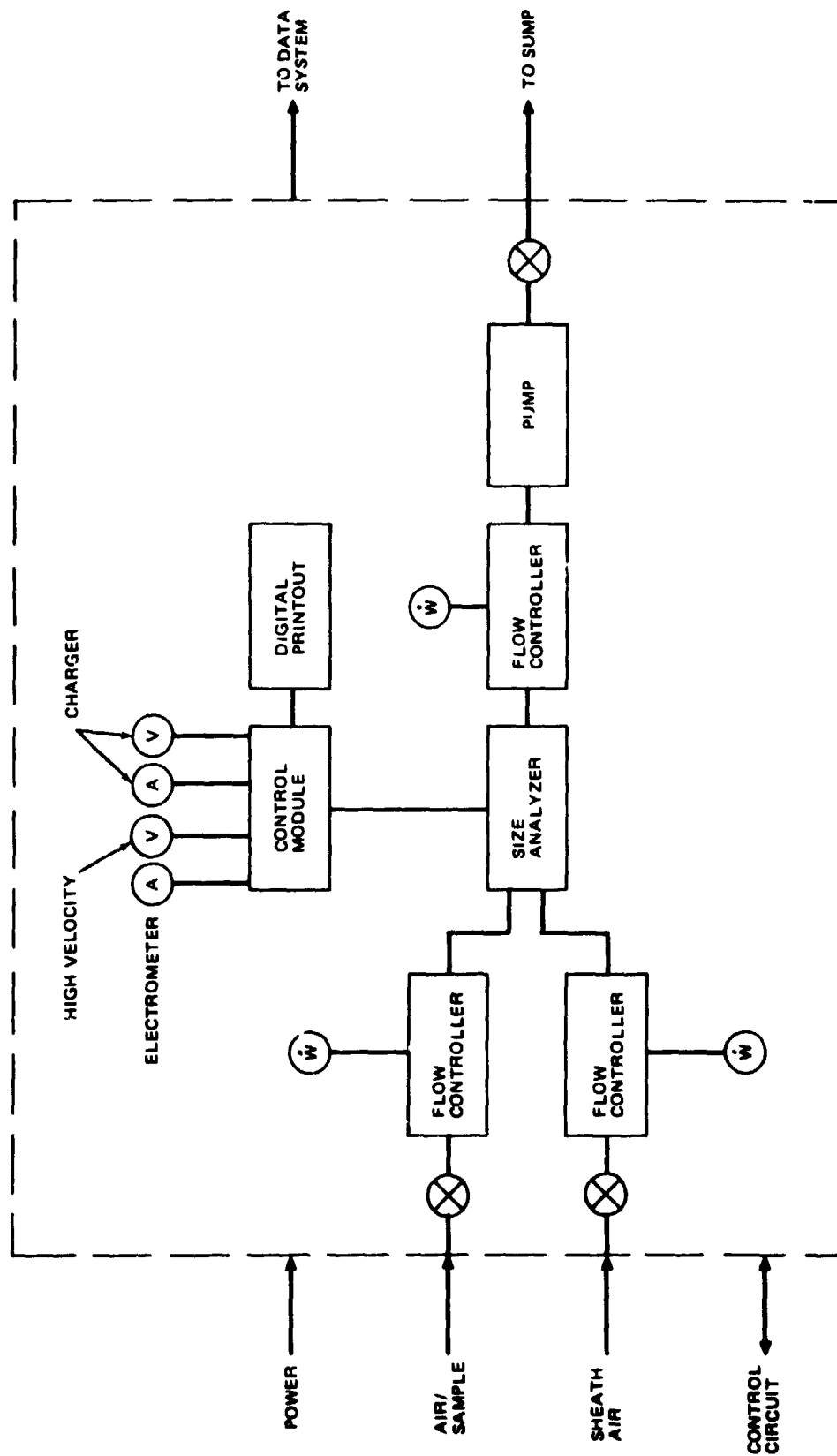
Figure 5-20. Electrical Aerosol Size Analyzer

history of various environments. These basic data can be obtained from each of the experiment classes (except Earth Simulation) as part of the data collection process. Previous experimental work has shown that the physical state of water and ice particles has a distinctive scattering signature. As data are collected during the experiments related to particle states and interactions, these additional data can be obtained optically without disturbing the experiment. The principle involves illuminating a particle with mono-chromatic light. The optical detector and its collecting aperture are rotated angularly about the particle as the Mie scattering intensity is recorded as a function of angle from light beam. Measurements are repeated using other light wavelengths. Polarization of the light beam will be used to determine its importance as an identifying feature. The data obtained would be

accumulated in a data bank. A remote sensor in a satellite or high-altitude aircraft would pass over a weather pattern and by virtue of the observed scattering signatures determine the suitability of the clouds to the triggering processes known as seeding for weather modification.

The instrument is not commercially available and would require development to be compatible with the experiment chambers. Since the measurements of scattering will be made as a function of angle with the light beam, the particles must be still. The scatterometer detector requires sensing from several angles within the chamber and requires a scan path guide rail so it can be moved around the periphery of the chamber. The scatterometer is an advanced development item and is the simplest of a series of three optical detectors (scatterometer, liquid water content meter, and drop size distribution meter). Figure 5-21 is a block diagram of this assembly.

5.4.9 Liquid Water Content Meter

The term, liquid water content (LWC) meter, is used here to mean an electro-optical system which measures the amount of vapor which has been condensed and provides a signal proportional to this quantity which can be used for control purposes. The parameters required to determine the LWC are: V_T-total sensitive volume of the chamber; n(a)-the size distribution or concentration of liquid particles, that is, the number of particles per unit volume per size range of particles (No. /cm^3/μm); and a - the radius of the particles. In general all of these variables are a function of time. Because, the condensible
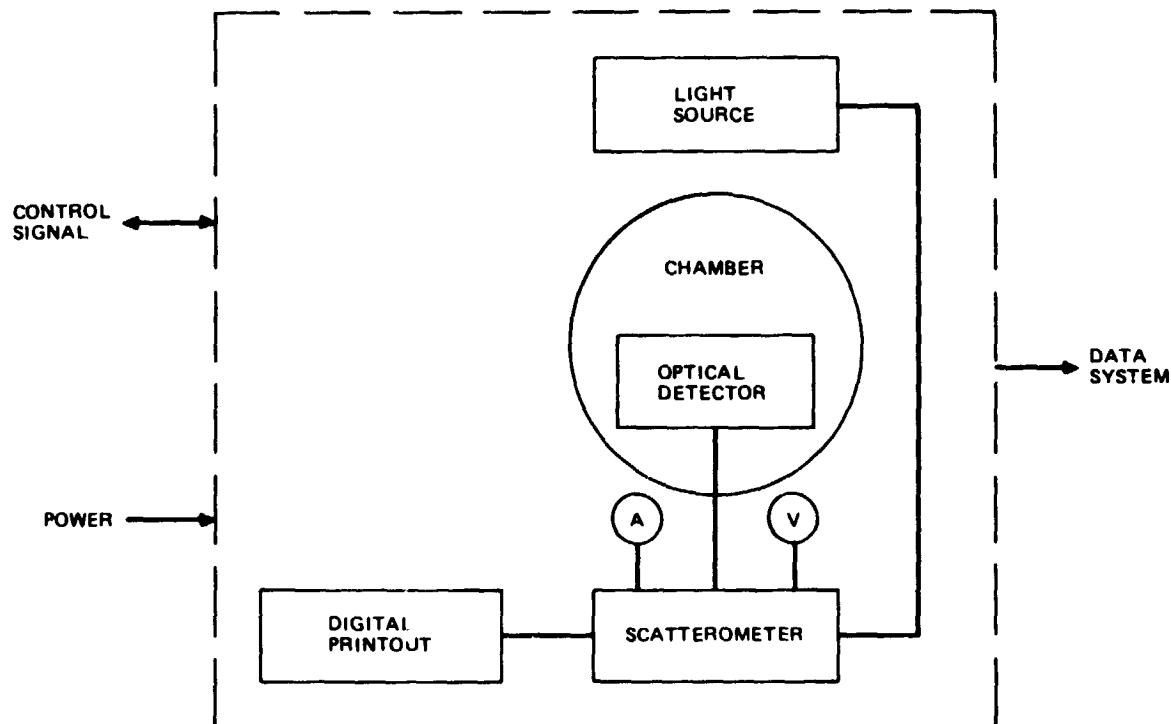
Figure 5-21. Scatterometer

vapor will be water, the discussion will be limited to spherical water droplets. With this assumption one can write the LWC as

$$LWC(t) = V_T(t) \ \frac{4\pi}{3} \int_u^v n \ \big[a(t)\big] \ \big[a(t)\big]^3 \ da$$

where u and v are the smallest and largest droplets present at time t. This is the general definition which for a monodispersed clou   educes to the simpler form

$$LWC(t) = V_T(t) \ \frac{4\pi}{3} \big[a(t)\big]^3 \ N$$

where N is the droplet concentration. Thus, to determine the LWC one must measure V_T, n(a), and a as a function of time. While the disymmetry ratio does not provide a means of measuring n(a) and a directly, the optical signals measured contain average information about n(a) and a from which the LWC can be obtained in an approximate form. To measure the disymmetry ratio three simultaneous measurements must be taken at fixed given angles. The instrument is not commercially available and is an advanced development item.

It is the second in the series of optical detectors to be developed. After the scatterometer is developed using a single detector this instrument using three detectors with fixed angle relationship would be developed. Figure 5-22 is a block diagram of the assembly.

5.4.10 Drop Size Distribution Meter

The following is a description of an instrument with which the size distribution of water droplets in a fog can be measured quickly and nondestructively in situ.

The particle size distribution is calculated from the characteristics of the diffraction pattern at infinity of a coherent beam passed through a sample. A laser source emits a continuous beam of coherent light, expanded by means of a beam expander, across the sample. Just beyond the sample a lens is positioned which allows observation of the diffraction pattern at infinity in its focal plane.

The diffraction pattern depends only on the dimensions of particles inside the chamber between the lenses where the sample is located. There are two
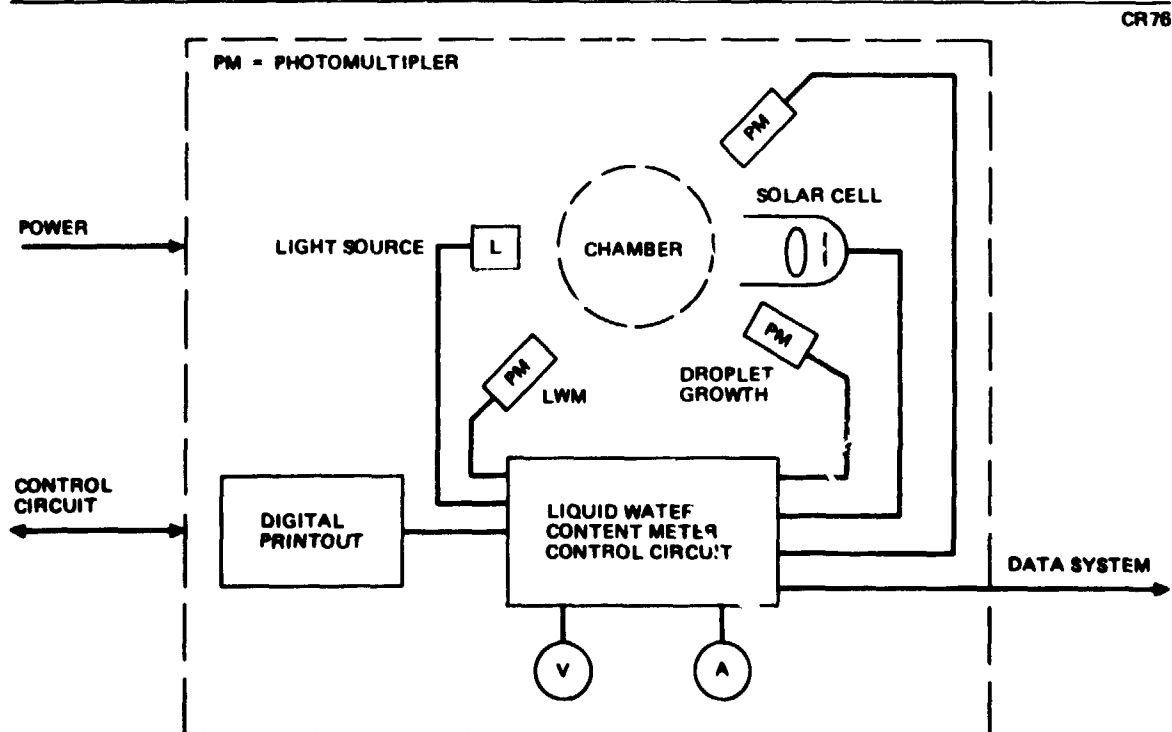
Figure 5-22. Liquid Water Content Meter

different patterns: the first one, very narrow, is due to the whole sample, and another one, broader, is due to the particles. If all the particles have the same size and shape (for example spherical), the second diffraction pattern is the well-known airy figure composed of alternating bright and dark rings around the central peak. Neglecting the central portion, the absolute luminous intensity may be related to the number of particles, for total diffracted light is proportional to the diffracting area. If the particles have different sizes, the nulls in the diffraction pattern become filled in, and the distribution becomes wider as particles are made smaller. Therefore, if the particles are polydispersed, precise information on size distribution cannot be obtained from a single observation, and photometric measurement has to be done. A multiple detector which samples the diffraction in polar coordinate form is convenient for imagery analyzers.

The precise diameter of small spherical particles can be determined by computer analysis of the scattering patterns. These measurements can be analyzed to determine the distribution of the particle sizes and their index of refraction. A block schematic of the assembly is shown in Figure 5-23.
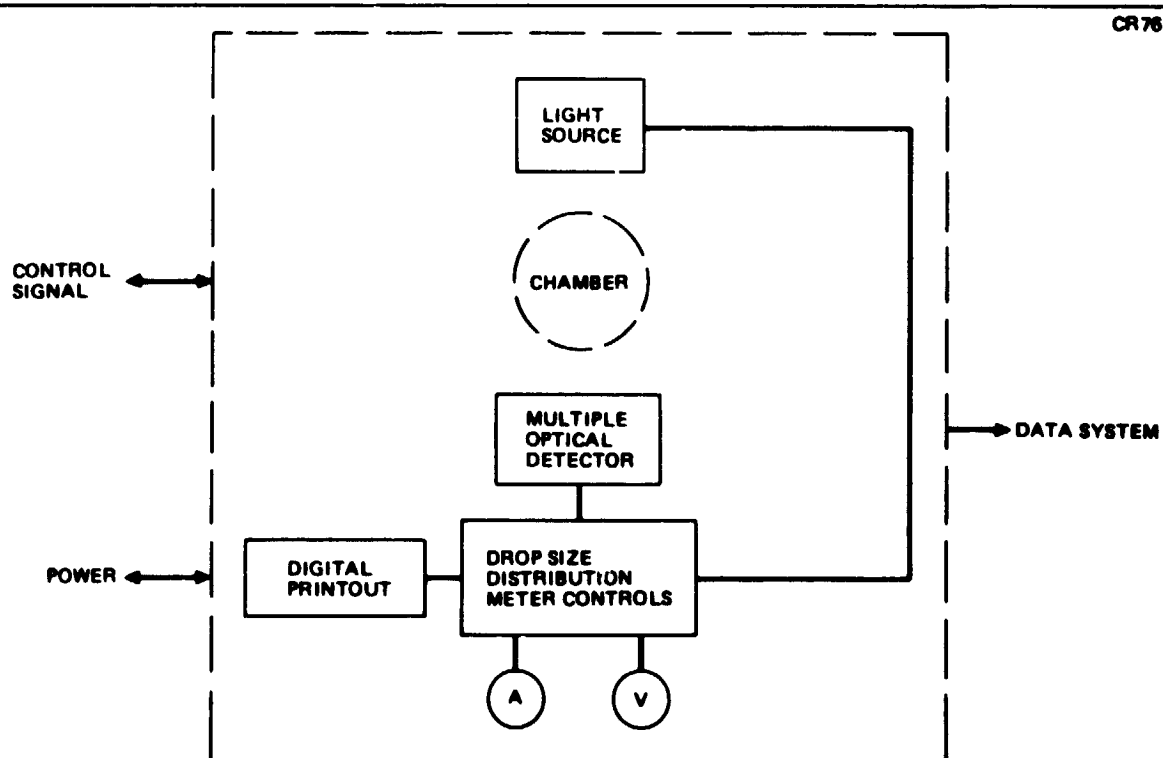
Figure 5-23. Drop Size Distribution Meter

This assembly is also an advanced development item. The drop size distribution meter utilizes up to 64 stationary detectors of a type similar to those of the scatterometer and liquid water content meter.

5.4.11 Optical Thermoelectric Dew Point Hygrometer

In this instrument a beam of light is reflected from a stainless steel mirror surface into a photoresistor which forms one leg of an optical bridge circuit. A second photoresistor is utilized to monitor the scattered light level from this mirror surface and to provide for ambient temperature compensation. When the mirror surface is dry the bridge is adjusted to an unbalanced condition, and the output corresponding to this unbalance is amplified and used to furnish direct current to the thermoelectric cooler. As the cooler pumps heat from the mirror surface, reducing its temperature, condensation occurs as the saturation temperature, or dew point, is reached. This condensation is detected by the reduction in the direct reflected light level, forcing the bridge toward the balance point, and thereby reducing the input signal to the amplifier. In this manner, an automatic closed-loop proportioning servo operation continuously maintains the mirror at an equilibrium temperature at which the rate of evaporation exactly equals the rate of condensation on the mirror. Independently, a platinum resistance thermometer embedded under the mirror surface provides a direct measurement of the temperature. This optical dew point technique is a fundamental measurement because the dew point temperature is the equilibrium saturation temperature corresponding to the water vapor partial pressure of the sample.

The overall range is from -65° C to +25° C with an accuracy of ±0.25° C. This technique is a primary measurement of the water vapor content of the gas. A block schematic of the assembly is shown in Figure 5-24.

5.4.12 Electric Dew Point Hygrometer

The electro-humidity sensor is an electric hygrometric circuit element which senses changes in relative humidity by changes in impedance. Since the humidity-sensitive portion of the sensor is restricted to the surface, water is sorbed or desorbed by means of adsorption instead of absorption. This results in a very rapid response to changes in relative humidity. The sensor is unaffected by environmental conditions that are not detrimental to cross-linked polystyrene; this includes most gases. Dust settling on the sensor surface will not affect performance except possibly to decrease the speed of response slightly. The sensing probe is automatically temperature
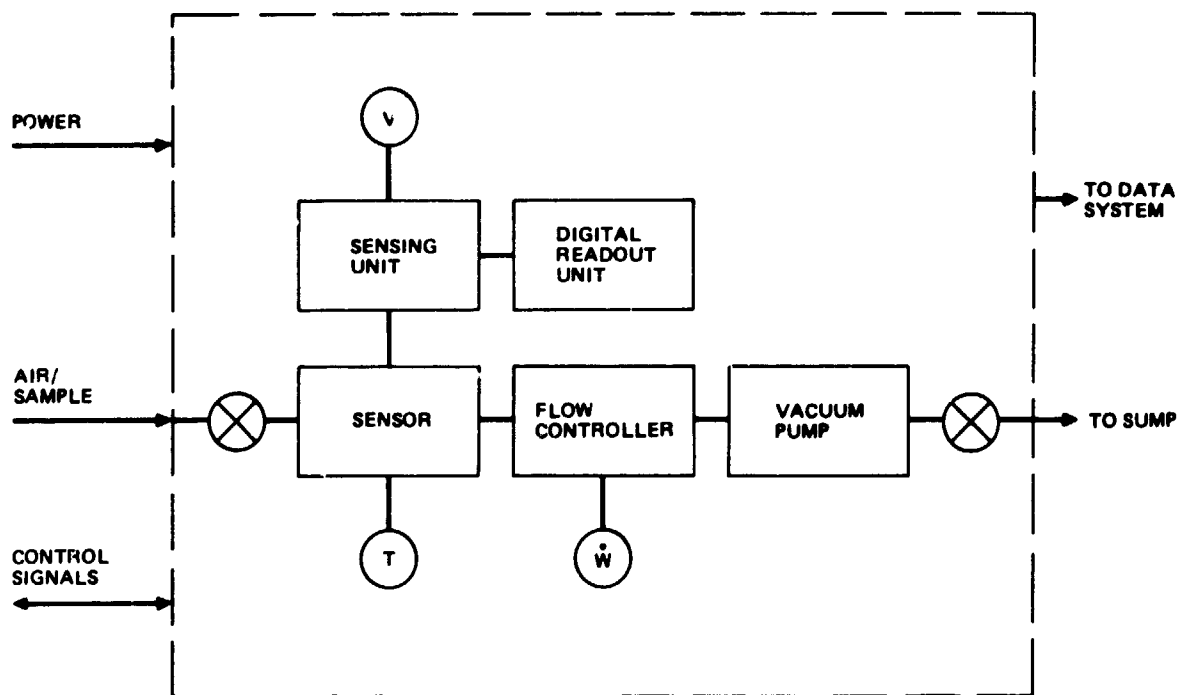
Figure 5-24. Optical Thermoelectric Dew Point Hygrometer

compensated for temperature changes from +5° C to +40° C. Outside the
compensated temperature range the instrument will read and hence may be
utilized by recalibration for any specific temperature from -70° C to +95° C.
The basic calibration accuracy is ± 2.5 percent RH for 0 percent to 100 per-
cent to 0 percent RH excursion. For a 50 percent RH the basic accuracy is
better than ± 1.25 percent. A block schematic of the assembly is shown in
Figure 5-25.

5.5 EXPERIMENT CHAMBERS AND AEROSOL CONDITIONING SUBSYSTEM

There are five basic cloud chambers utilized in microphysics research which
are applicable to zero-gravity experiments. The continuous flow diffusion,
static diffusion liquid, and static diffusion ice chambers operate on a thermal
vapor diffusion principle to provide controlled supersaturated conditions.
These chambers require thermally controlled surfaces which are water or
ice covered. The expansion and general chambers require thermally con-
trolled surfaces. These chambers are used to define the relative humidity,
pressure, and temperature environment for the experiments. This includes
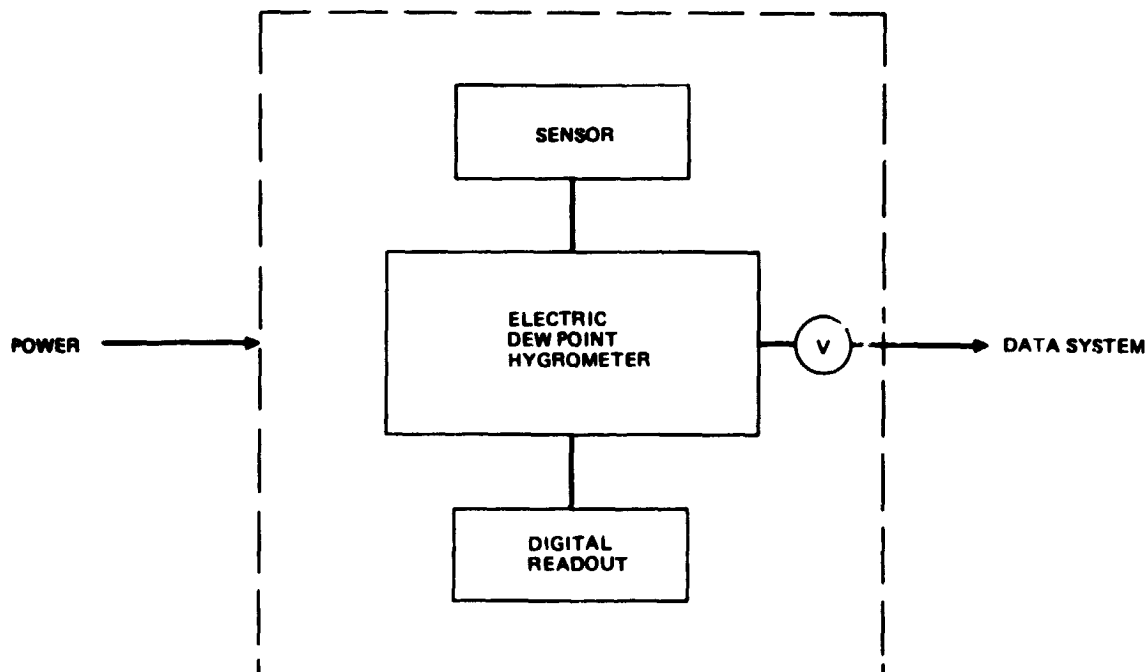
Figure 5-25. Electric Dew Point Hygrometer

all subsystems and assemblies associated with physical experiment volume encompassing the following items:

A. Chamber wall assemblies including thermal control elements.

B. Equipment mounting ports, optical observation ports, and related items for access to the experiment volume. These items provide access for data acquisition and particle injection.

C. Electric/optic/acoustic environment control subassemblies.

D. Instrumentation and display subassembly sensors and displays which are utilized for control and visual display.

In addition to the cloud chambers an earth simulation chamber will simulate certain aspects of planetary and solar convection with its attendant differential rotation. Also a nuclei conditioning chamber is utilized to store and condition nuclei for the various experiments.

The chambers to be used in CPL experimentation are shown in Figure 5-26. The pertinent geometric features, the significant operational features, the use, and the primary requirements are also identified in this figure. The requirements specified are compatible with the experiment class usage as primary and alternate cloud chambers.

Table 5-11 is a summary of the primary and alternate chamber assignments by experiment class.

This subsystem includes the following assemblies:

    A.   Static diffusion liquid chamber (SDL)

    B.   Static diffusion ice chamber (SDI)

    C.   General chamber (G)

    D.   Expansion chamber (E)

    E.   Continuous flow diffusion (CFD)

    F.   Earth simulation chamber

    G.   Nuclei conditioning chamber

Weight, power, and volume are given by chamber on Table 5-12.

5.5.1   Static Diffusion Liquid (SDL) Chamber

Present configurations of this chamber are generally patterned after the 1963 design of Twomey. The thermal diffusion principle originated with Langsdorf (1936) and modified by Wieland (1936). In this type of instrument two horizontal wet surfaces are spaced 1.5 cm apart. The surface of the bottom plate is maintained approximately 0° C to 10° C colder than the top plate in order to produce the desired supersaturations.

Diffusion of heat and water vapor from the warmer toward the colder surface produces linear temperature and vapor pressure gradients. Because the saturation vapor pressure versus temperature curve is concave upward, the actual water vapor pressure exceeds the saturation vapor pressure (because of the linear gradients) between the two plates and continually produces a supersaturation which is a maximum near the midpoint between the plates.

	CONTINUOUS-FLOW DIFFUSION (CFD) $T_2 < T_1$ LIQUID SURFACES 0.01 μm < PARTICLE DIAMETER < 10 μm OUTPUT – SIZE DISTRIBUTION CONDENSATION NUCLEATION STUDIES	STATIC DIFFUSION, LIQUID (SDL) $T_2 < T_1$ LIQUID SURFACES 0.01 μm < PARTICLE DIAMETER < 10 μm OUTPUT – NUMBERS ONLY CONDENSATION NUCLEATION STUDIES	STATIC DIFFUSION, ICE (SDI) $T_2 < T_1$ ICE SURFACES 1 μm < PARTICLE DIAMETER < 1 cm OUTPUT – SIZE, SHAPE ICE CRYSTAL STUDIES
PRESSURE RANGE TOLERANCE	760 TO 700 mm ABS ± 5 mm REL ± 1 mm	760 TO 140 mm ABS ± 10 mm REL ± 1 mm	760 TO 140 mm ABS ± 10 mm REL ± 1 mm
RELATIVE HUMIDITY TOLERANCE	100% TO 103% ABS ± 0.02% REL ± 0.01%	100% TO 103% ABS ± 1% REL ± 0.5%	80% TO 120% ABS ± 1% REL ± 0.5%
TEMPERATURE TOLERANCE	0°C TO +35°C ABS ± 0.1°C REL ± 0.02°C	0°C TO +35°C ABS ± 0.1°C REL ± 0.02°C	-60°C TO +35°C ABS ± 1°C REL ± 0.1°C
$\Delta T\ (T_1 - T_2)$	0 TO 10°C	0 TO 10°C	0 TO 60°C
FLOW RATE	0.25 SCFM		

Figure 5-26. Cloud Chambers (Sheet 1 of 2)

	EXPANSION (E)	GENERAL (G)	EARTH SIMULATION (ES)
	HYDROPHOBIC SURFACES COOLED WALLS 0.01 μm < PARTICLE DIAM. ETER < 100 μm ADIABATIC EXPANSION OUTPUT – NUMBERS, MEAN SIZE CLOUD SIMULATION STUDIES	ELECTRIC FIELDS DROPLETS > 100 μm LARGE-PARTICLE INTERACTIONS	DIFFERENTIALLY HEATED ROTATING SPHERICAL ANNULUS OF FLUID ROTATION RATE – 6 RAD/SEC PLANETARY AND SOLAR CONVECTION STUDIES
PRESSURE RANGE	760 TO 140 mm	760 TO 140 mm	AMBIENT
TOLERANCE	ABS ± 2 mm REL ± 0.1 mm	ABS ± 10 mm REL ± 1 mm	N/A
RELATIVE HUMIDITY	1 TO 100%	1 TO 95%	N/A
TOLERANCE	ABS ± 1% REL ± 0.5%	ABS ± 1% REL ± 0.5%	– –
TEMPERATURE	–40°C TO +35°C	–10°C TO +35°C	+15°C TO +35°C
TOLERANCE	ABS ± 0.5°C REL ± 0.05°C	ABS ± 1°C REL ± 0.1°C	ABS ± 0.1°C REL ± 0.03°C
ΔT (T$_1$ – T$_2$)	–	–	0 TO 7°C

Figure 5-28. Cloud Chambers (Sheet 2 of 2)

Table 5-11
PRIMARY AND ALTERNATE CHAMBER SELECTION

Class No.	Class Title	Primary Chamber	Alternate Chamber
1	Condensation Nucleation	CFD	E
2	Ice Nucleation	SDI	E
3	Ice Multiplication	SDI	E
4	Charge Separation	SDI	G
5	Ice Crystal Growth Habits	SDI	E
6	Scavenging	SDI	G
7	Riming and Aggregation	SDI	G
8	Droplet-Ice Cloud Interactions	SDI	E
9	Homogeneous Nucleation	SDI	E
10	Collision-Induced Freezing	SDI	G
11	Saturation Vapor Pressure	SDI	E
12	Adiabatic Cloud Expansion	E	-
13	Ice Nuclei Memory	E	SDI
14	Terrestrial Expansion Chamber Evaluation	E	-
15	Condensation Nuclei Memory	E	SDL
16	Nuclei Multiplication	G	E
17	Drop Collision Breakup	G	SDI
18	Coalescence Efficiencies	G	SDI
19	Static Diffusion Chamber Evaluation	SDL	-
20	Unventilated Droplet Diffusion Coefficients	SDL	E
21	Earth Simulation	ES	-

Table 5-12
EXPERIMENT CHAMBERS AND AEROSOL CONDITIONING SUBSYSTEM FEATURES BY CHAMBER

Chamber	Weight (kg)	Volume (m³)	Power Maximum Operating (watts)	Power Nominal Operating (watts)	8-Hr Average Power (watts)
Static Diffusion (Liquid)	6.51	0.0043	255	105	52.5
Static Diffusion (Ice)	40.39	0.077	1,345	385	71.5
General	41.48	0.093	1,135	345	75.5
Expansion	101.41	0.310	1,405	415	69
Continuous Flow Diffusion	25.33	0.073	325	115	69.5
Earth-Simulation	24.56	0.064	255	85	65
Nuclei Conditioning	89	0.306	335	95	58.5

One water droplet forms on each of those nuclei pre. if which are activated at the low supersaturation. These droplets are illuminated by a well-defined light beam which passes across the center of the space between the plates. These droplets may be counted individually or the number may be indicated by detecting the integrated light scattered by the cloud of droplets. Photographic recording of the individual droplets for subsequent counting is usually used while a video camera, monitor, and recorder permit real-time observation of the peak concentration of droplets and permit, with stop action, counting on the TV screen. Counting of droplet images has the advantage of being more nearly independent of droplet size and growth rate. But if the light level is marginal, there may be loss of detection of smaller droplets or lack of discrimination between images and film imperfections.

The internal dimensions of the SDL chamber are given in Figure 5-27. Thermal and relative humidity control on the input sample is only that required for appropriate sample conditioning. The relative humidity and temperature within the chamber are both controlled by the wall thermal control. The vertical and horizontal dimensions of the chamber working volume are dictated by laws of physics apart from gravity factors along with the conditions required by the phenomena to be studied. Required response times of about 1 second for condensation nucleation experiments dictate a depth of 1.5 cm and phot ere hic requirements limits the diameter to 15 cm. A block diagram of the assembly is shown on Figure 5-28.

Weight, power, and volume is given by assembly on Table 5-13.

5.5.1.1 Chamber Wall Subassembly
Four basic chambers (SDL, SDI, G, E) will have their respective thermally cooled walls formed from utilized wall modules consisting of heat pipe cavity wall surfaces, thermoelectric modules, insulation, heat exchanger/manifold, and outer wall shell. The thermoelectric power and heat sink coolant fluid will be supplied through appropriate separable connectors. The configuration for the top and bottom wall modules is shown in Figure 5-27.

PORT CONFIGURATION

INTERNAL VOLUME

LIGHT TRAP

IMAGE DETECTION

LIGHT SOURCE

VIEWING

TOP/BOTTOM WALLS

WATER WICKING SURFACE

HEAT PIPES

THERMO ELECTRIC MODULE

HEAT EXCHANGER

SPRINGS

COOLANT RETURN

COOLANT DISTRIBUTION MANIFOLD

INSULATION

OUTER SHELL

COOLANT FLUID INLET

1.5 CM

15 CM DIA

SIDE WALLS AND OPTICAL VIEW PORTS

OUTER WALL

OPTICAL GRADE PLATES

INSULATION

THERMAL CONDUCTING WALL

ANTI FOG SURFACE

EVACUATED THERMAL BARRIER

Figure 5-27. Static Diffusion Liquid Chamber
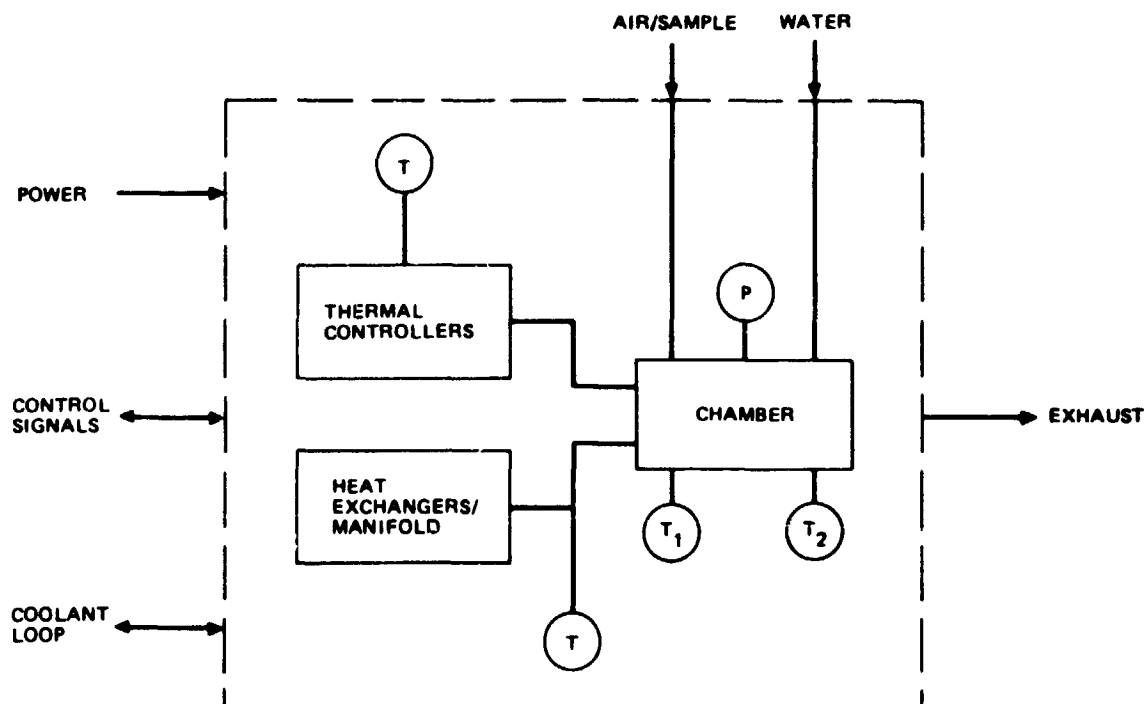
Figure 5-28. Static Diffusion Liquid Chamber

Table 5-13

STATIC DIFFUSION LIQUID CHAMBER FEATURES BY ASSEMBLY

Assemblies	Weight (kg)	Volume (m³)	Power Maximum Operating (watts)	Power Nominal Operating (watts)	% Usage Experiment Time	8-Hr Average Power (watts)
Chamber Subassembly	4.61	0.003	-			
Thermal Controllers	0.91	0.0003	250	100	50	50
Instrumentation and Display	1.0	0.001	5.0	5.0	50	2.5
Totals	6.52	0.0043	255	105		52.5

5.5.1.2 Optical Ports

The orientation and function of the three optical ports are indicated in Figure 5-27. The inside and outside surfaces of these ports will be of high optical grade material to permit undistorted visual observation and photographic recording of the central chamber volume. Visible wavelengths will be used. The inner port surface will require antifogging, either by special coating or by controlled heating of the surface. The port unit is evacuated to minimize the thermal transport into the chamber. Anti-reflective coatings will also be required to maximize transmission and minimize scattering.

5.5.1.3 Equipment Mounting Ports

Universal mounting brackets which permit quick equipment removal and inter-change will be required on each optical port. One mount is for the light source which provides illumination of the droplets within the chamber. At 90 degrees to the light port will be a combination camera/visual port. The third port will have provisions for mounting a vidicon. This latter port will also be utilized for direct visual observations.

5.5.1.4 Water Wicking Surfaces

The top and bottom walls will be covered with a fine-mesh screen material or equivalent capillary material to provide two moist surfaces. These wet surfaces provide the water source for controlling the chamber relative humidity. The fluid surfaces are less than 0.3 mm thick and are in intimate contact with the heat pipe wall surfaces. Water is supplied to one part of each surface and the capillary action of the surface insures uniform and total coverage of this surface.

5.5.1.5 Light Trap

The light trap absorbs the chamber illumination light after this light has passed through the chamber. The photography requires dark-field illumination with minimal background scattered light. A very effective configuration for a light trap is shown in Figure 5-27. The shape is similar to a horn of plenty with an appropriate internal absorbing surface. Air cooling requirements will be a function of the absorbed optical power. An optical port may also be needed to satisfy thermal requirements.

5.5.1.6 Thermal Controllers

Closed-loop thermal control will be used to provide the necessary temperature control of the top and bottom plates. The thermoelectric modules require dc power with less than 2 percent ac ripple component. Thermistor sensors imbedded in the plate surfaces provide the feedback signal to the controllers. The top plate is controlled at a set temperature while the lower plate is slaved to the top plate with a set temperature difference. Control range is 0° C to 35° C.

5.5.1.7 Instrumentation and Display Subassembly

Pressure and temperature transducers will be used within the chamber to monitor system status and performance. Appropriate readout locations are shown on Figure 5-28.

5.5.2 Static Diffusion Ice Chamber Assembly

The principles of physics governing the operation of this chamber are the same as described for the static diffusion liquid chamber. This chamber is operated below freezing using ice surfaces rather than water surfaces. The growth of ice crystals to millimeter dimensions requires times extending to tens of minutes thus permitting a larger geometric configuration for this chamber. Thermal considerations influence the diameter-to-height ratio thus dictating the internal dimensions shown in Figure 5-29. The experiments associated with this chamber also require the attachment of a number of auxiliary devices for which connections and ports are provided. A block diagram of the associated items for this assembly are shown in Figure 5-30.

Weight, power, and volume is given by assembly on Table 5-14.

5.5.2.1 Chamber Wall Subassembly

All of the walls of the SDI chamber are formed from the same modular units as used by the SDL chamber. The larger surface area requires an increase in the number of thermoelectric module elements. Figure 5-29 illustrates the heat pipe/thermoelectric/insulation and heat exchanger/manifold configuration and these units are described in the SDL chamber discussion.

PORT CONFIGURATION

INTERNAL VOLUME

10 CM

40 CM DIA

Y ACOUSTIC DETECTION

Z ACOUSTIC SOURCE AND DETECTION

AEROSOL INJECTION

LIGHT TRAP

X ACOUSTIC SOURCE

SCATTEROMETER SCAN PATH

DROPLET INJECTION

LIGHT SOURCE

Y ACOUSTIC SOURCE

IMAGE DETECTION

LIGHT SOURCE/ IMAGE DETECTION

X ACOUSTIC DETECTION

OPTICAL HEATING

DROPLET/ICE INJECTION

LIGHT TRAP

45°

45°

TOP/BOTTOM WALLS

ELECTRIC FIELD PLATE

WATER WICKING SURFACE

HEAT PIPES

THERMOELECTRIC MODULE

HEAT EXCHANGER

SPRINGS

COOLANT RETURN

COOLANT DISTRIBUTION MANIFOLD

INSULATION

OUTER SHELL

COOLANT FLUID INLET

SIDE WALLS AND OPTICAL VIEW PORTS

OUTER WALL

OPTICAL GRADE PLATES

INSULATION

THERMAL CONDUCTING WALL

ANTI FOG SURFACE

EVACUATED THERMAL BARRIER

Figure 5-29. Static Diffusion Ice Chamber
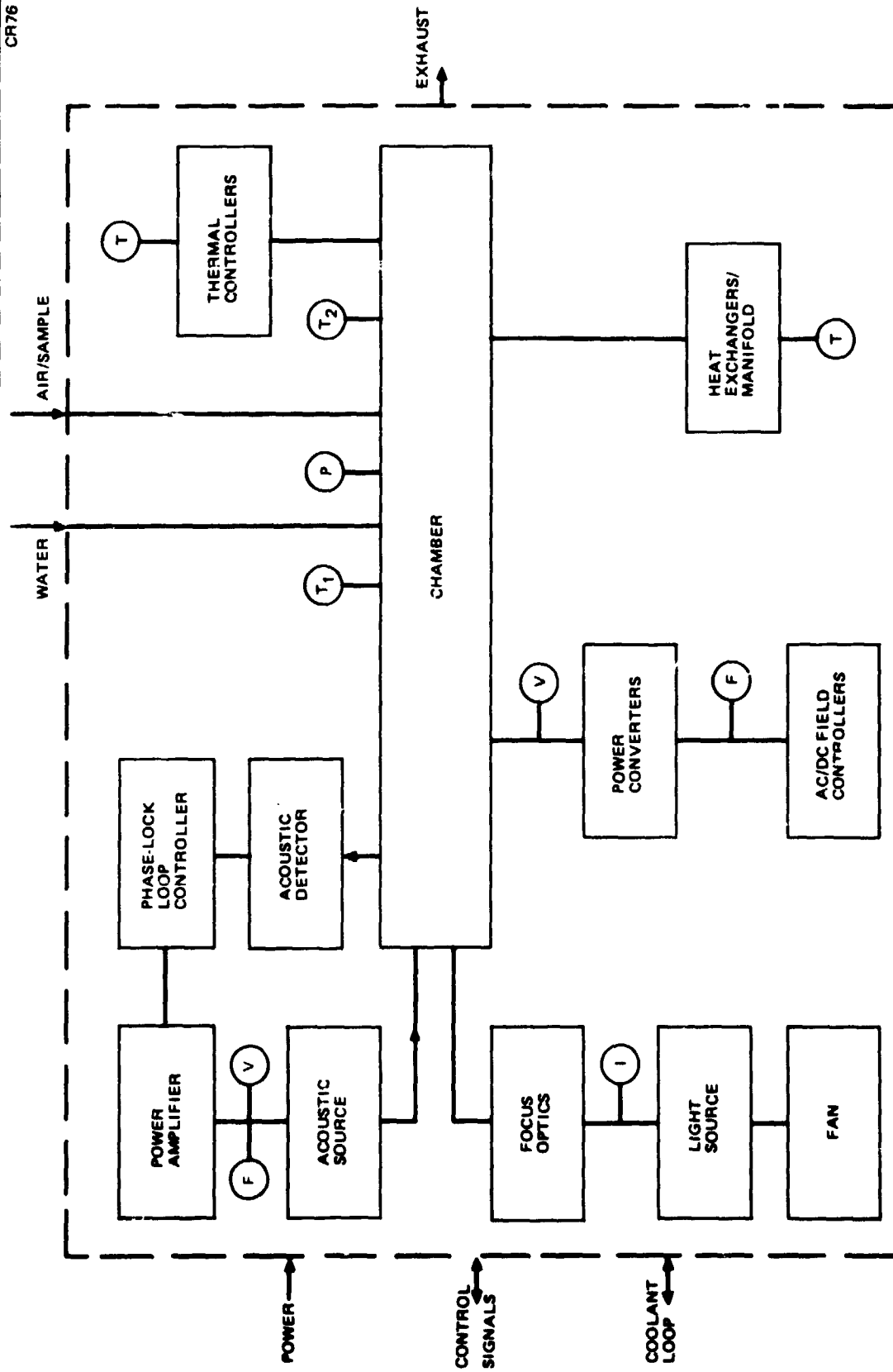
Figure 5-30. Static Diffusion Ice Chamber

Table 5-14

STATIC DIFFUSION ICE CHAMBER FEATURES BY ASSEMBLY

Assemblies	Weight (kg)	Volume (m³)	Power Maximum Operating (watts)	Power Nominal Operating (watts)	% Usage Experiment Time	8-Hr Average Power (watts)
Chamber Subassembly	19.24	0.047	-	-		
Electric Field Subassembly	9.225	0.017	40	10	5	0.5
Optical Conditioning Subassembly	4.53	0.01	750	150	5	7.5
Acoustical Subassembly	2.27	0.003	40	10	5	0.5
Scatterometer Interface	2.27	0.0014	10	10	5	0.5
Thermal Controllers	1.82	0.0006	500	150	40	60
Instrumentation and Display	1.0	0.001	5	5	50	2.5
Totals	40.39	0.077	1,345	385	-	71.5

5.5.2.2 Optical Ports

The port configuration is given in Figure 5-29. Three of the optical ports function similarly as in Subsection 5.5.1.2. The universal mounting associated with each port permits the attachment of auxiliary optical equipment as required by a given experiment. The light source will illuminate the central portion of the chamber through one of the ports. At 45 degrees from the illumination port, image detection by camera and visually will be made where the camera provides hard copy for future analysis and simultaneous visual observations permit real time experiment critiquing. A third port 90 degrees from the light source provides for additional illumination when required but will also permit the use of TV camera and display to provide quick, nonfatigue monitoring of the experiment progress. In addition, certain experiments will require that this port have a special 10-μm infrared transmitting material to permit the observation and recording of ice crystal surface temperature profile.

Optical heating will also require special broadband infrared transmission. The heating will be provided by an appropriately focused and controlled infrared source.

5.5.2.3 Equipment Mounting Ports

A universal, quick-disconnect mounting will be required at the four optical ports in addition to those required for the nonoptical equipment. The port configuration is shown in Figure 5-29. Three acoustic source/detection pairs (six places) are required for motion control in addition to the two required for the light traps. Two more mounting ports are required for droplet/ice and droplet injection generators with a third for direct aerosol injection into the ice chamber.

5.5.2.4 Water Wicking Surfaces

These surfaces are illustrated in Figure 5-29. Water is supplied as in the SDI while the SDI chamber is above freezing. Once the surfaces have been appropriately covered, the water surfaces are frozen as needed for the suceeding experiments. Replenishment of the ice surface will be done at the start of each 8- to 10-hour experiment period.

5.5.2.5 Electric Field Subassembly

This subassembly will provide a uniform electric field in which ice crystals can be grown and within which dynamic studies between combinations of droplets and ice will be made in relation to cloud electrification processes.

5.5.2.6 Optical Conditioning Subassembly

This subassembly as used in this chamber provides remote heating of droplet or ice crystals within the chamber. This heating is accomplished by focusing infrared (IR) energy onto the appropriate object.

5.5.2.7 Acoustical Subassembly

This subassembly provides motion and orientation control of droplets/ice crystals within the chamber. Appropriate sensor feedback is provided so that the field energy is negligible until the constrained object moves beyond prescribed boundaries. Some of the experiments require exact orientation control of an ice crystal. In these cases, the acoustic field will be required on a more continuous basis but at a level which is four or five decades below the equivalent field that would be required in a terrestrial laboratory for the same objective. These low levels of acoustic field will not appreciably affect those particular experiments for which the field will be required. Three axis controls will be required. Physical configuration is illustrated in Figure 5-29.

5.5.2.8 Scatterometer Interface Equipment

The scatterometer detector requires sensing from several angles within the chamber and the liquid water content meter requires optical intensity detection from two simultaneous angles. This interface equipment includes the sensor mountings, scan path guide rail, and stepping motor position control with optical angle encoder readout.

5.5.2.9 Light Trap

The light trap absorbs the chamber illumination light after this light has passed through the chamber. The photography requires dark field illumination with minimal background scattered light. A very effective configuration for a light trap is shown in Figure 5-29. The shape is similar to a horn of

plenty with an appropriate internal absorbing surface. Air-cooling requirements will be a function of the absorbed optical power. An optical port may also be needed to satisfy thermal requirements.

5.5.2.10 Thermal Controllers

Closed-loop thermal control will be used to provide the necessary temperature control of the top and bottom plates. The thermoelectric modules require dc power with less than 2 percent ac ripple component. Thermistor sensors embedded in the plate surfaces provide the feedback signal to the controllers. The top plate is controlled at a set temperature while the lower plate is slaved to the top plate with a set temperature difference. Control range is -35°C to +35°C, with limited operation time below -32°C.

5.5.2.11 Instrumentation and Display Subassembly

Pressure and temperature transducers will be used within the chamber to monitor system status and performance. Appropriate readout locations are shown on Figure 5-30.

5.5.3 General Chamber

The general chamber provides homogeneous temperature, relative humidity, and pressure-controlled environment for the performance of experiments which involve dynamic interactions between various combinations of ice crystals and droplets. The geometry is optimized for the production, control, and observation of the desired interaction. Initial relative humidity and pressure controls are provided by external means while all of the chamber walls are thermally controlled in the same way as for the SDI and SDL top and bottom walls. The internal volume specifications are given in Figure 5-31 along with other related details. Figure 5-32 is a block diagram relating the various subassemblies associated with the general chamber.

Weight, power, and volume is given by assembly on Table 5-15.

5.5.3.1 Chamber Wall Subassembly

All of the walls of the general chamber will have the same modular construction as the top and bottom walls of the SDL and SDI chambers. Allowances are made for the various optical ports and equipment mounting ports. The

PORT CONFIGURATION

Z ACOUSTIC SOURCE/DETECTION

SCATTEROMETER SCAN PATH

RELATIVE HUMIDITY SENSOR

LIGHT TRAP

X ACOUSTIC SOURCE

DROPLET INJECTION

LIGHT SOURCE

LIGHT TRAP

Y ACOUSTIC SOURCE

DROPLET INJECTION

OPTICAL HEATING/MOTION CONTROL

LIGHT SOURCE/IMAGE DETECTION

X ACOUSTIC DETECTION

IMAGE DETECTION

Y ACOUSTIC DETECTION

INTERNAL VOLUME

15 CM

30 CM

10 CM

15 CM

10 CM

ALL WALLS

ELECTRIC FIELD PLATE (TOP/BOTTOM WALLS ONLY)

HEAT PIPES

THERMOELECTRIC MODULE

HEAT EXCHANGER

SPRINGS

COOLANT RETURN

COOLANT DISTRIBUTION MANIFOLD

INSULATION

OUTER SHELL

COOLANT FLUID INLET

OPTICAL VIEWPORTS

OUTER WALL

OPTICAL PLATES GRADE

INSULATION

ANTI FOG SURFACE

EVACUATED THERMAL BARRIER

Figure 5-31. General Chamber

5-63
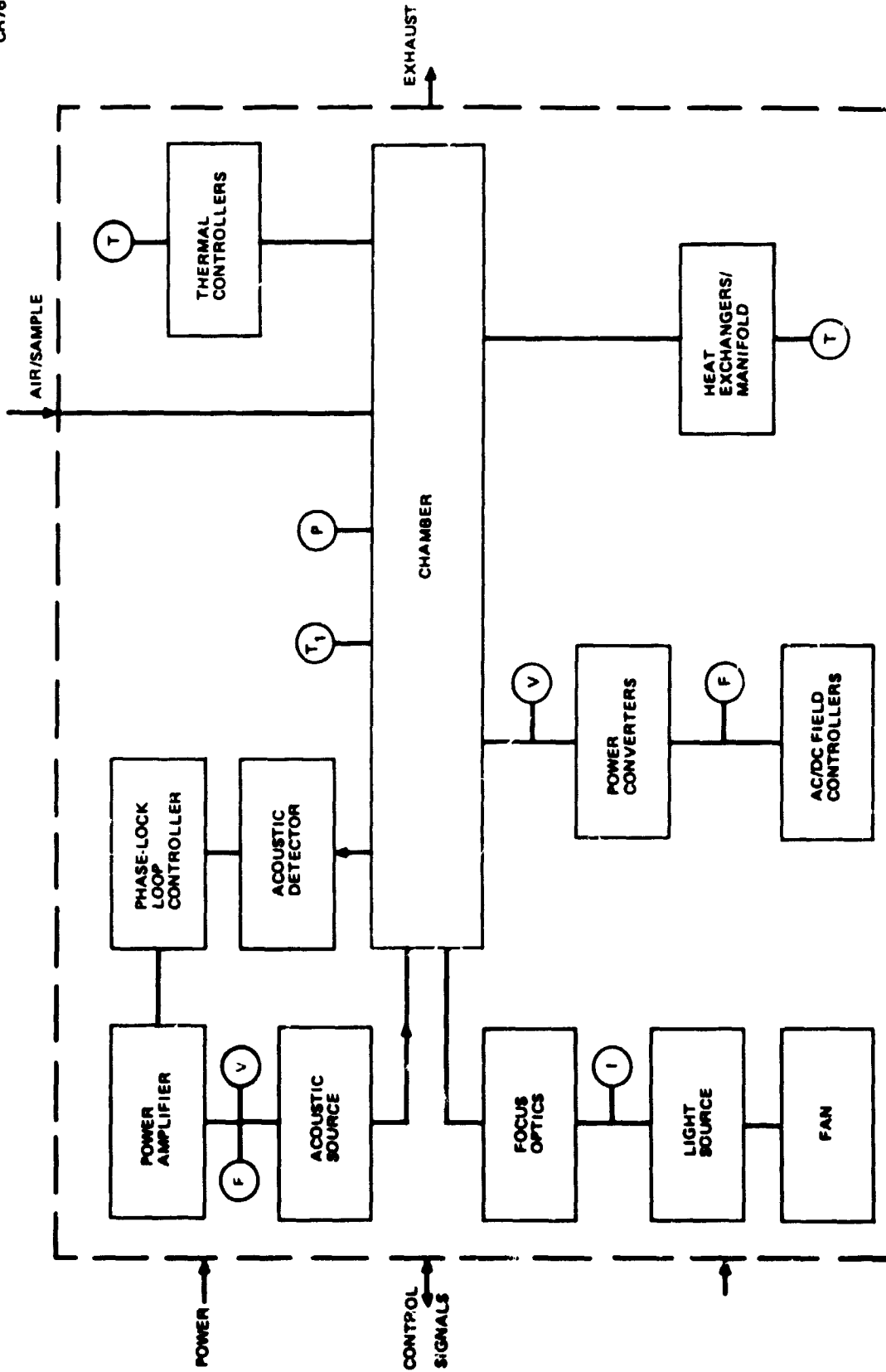
Figure 5-32. General Chamber

Table 5-15

GENERAL CHAMBER FEATURES BY ASSEMBLY

Assemblies	Weight (kg)	Volume (m³)	Power Maximum Operating (watts)	Power Nominal Operating (watts)	% Usage Experiment Time	8-Hr Average Power (watts)
Chamber Subassembly	21.28	0.065	-			
Electric Field Subassembly	9.225	0.015	40	10	5	0.5
Optical Conditioning Subassembly	4.53	0.01	750	150	5	7.5
Acoustical Subassembly	2.26	0.0014	80	20	20	4.0
Scatterometer Interface	2.27	0.0014	10	10	10	1.0
Thermal Controller	0.91	0.0003	250	150	40	60
Instrumentation and Displays	1.0	0.001	5	5	50	2.5
Total	41.48	0.093	1,135	345		75.5

major difference is that the general chamber will require thermoelectric cooling on all side surfaces in addition to the top and bottom walls.

5.5.3.2 Optical Ports

The port configuration is given in Figure 5-31. The universal mounting associated with each port permits the attachment of auxiliary optical equipment as required by a given experiment. The light source will illuminate the central portion of the chamber through one of the ports. At 45 degrees from the illumination port, image detection by camera and visual will be made where the camera provides hard copy for future analysis and simultaneous visual observations permit real time experiment critiquing. A third port 90 degrees from the light source provides for additional illumination when required but will also permit the use of TV camera and display to provide quick, nonfatigue monitoring of the experiment progress. In addition, certain experiments will require that this port have a special 10-μm infrared transmitting material to permit the observation and recording of ice crystal surface temperature profile.

Optical heating will also require special broadband infrared transmission. The heating will be provided by an appropriately focused and controlled infrared source.

5.5.3.3 Equipment Mounting Ports

A number of quick-disconnect type of equipment mountings are required. In addition to a mounting at the four observation ports, there are required ports and mountings for (1) three acoustic source/detector pairs (six ports) for motion control, (2) two diagonally opposite droplet injection ports, (3) relative humidity measurement port, and (4) two light trap ports.

5.5.3.4 Electric Field Subassembly

This subassembly will provide a uniform electric field in which ice crystals can be grown and within which dynamic studies between combinations of droplets and ice will be made in relation to cloud electrification processes.

5.5.3.5 Optical Conditioning Subassembly

This subassembly as used in this chamber provides remote heating of droplet or ice crystals within the chamber. This heating is accomplished by focusing IR energy onto the appropriate object. The additional requirement of optical positioning requires a highly configured light beam of a non-water-absorbing wavelength. The wavelength selection will be accomplished by use of an optical filter or alternate light source.

5.5.3.6 Acoustical Subassembly

This subassembly provides motion and orientation control of droplets/ice crystals within the chamber. Appropriate sensor feedback is provided so that the field energy is negligible until the constrained object moves beyond prescribed boundaries. Some of the experiments require exact orientation control of an ice crystal. In these cases, the acoustic field will be required on a more continuous basis but at a level which is four or five decades below the equivalent field that would be required in a terrestrial laboratory for the same objective. These low levels of acoustic field will not appreciably affect those particular experiments for which the field will be required. Three axis controls will be required. Physical configuration is illustrated in Figure 5-31.

5.5.3.7 Scatterometer Interface Equipment

The scatterometer detector requires sensing from several angles within the chamber and the liquid water content meter requires optical intensity detection from two simultaneous angles. This interface equipment includes the sensor mountings, scan path guide rail, and stepping motor position control with optical angle encoder readout.

5.5.3.8 Light Trap

The light trap absorbs the chamber illumination light after this light has passed through the chamber. The photography requires dark field illumination with minimal background scattered light. The shape is similar to a horn of plenty with an appropriate internal absorbing surface. Air-cooling requirements will be a function of the absorbed optical power. An optical port may also be needed to satisfy thermal requirements.

5.5.3.9 Thermal Controllers

Closed-loop thermal control will be used to provide the necessary temperature control of the top and bottom plates. The thermoelectric modules require dc power with less than 2 percent ac ripple component. Thermistor sensors embedded in the plate surfaces provide the feedback signal to the controllers. The top plate is controlled at a set temperature while the lower plate is slaved to the top plate with a set temperature difference. Control range is -10°C to +35°C.

5.5.3.10 Instrumentation and Display Subassembly

Pressure and temperature transducers will be used within the chamber to monitor system status and performance. Appropriate readout locations are shown on Figure 5-32.

5.5.4 Expansion Chamber Assembly

The expansion chamber provides cooling and supersaturation control by controlled adiabatic expansion. The walls are cooled in synchronization with the expansion cooling of the gas, thus providing for long-term, natural-cloud, adiabatic simulation. The advantages of the expansion chamber include uniform humidity, temperature, and pressure throughout the chamber as would exist in the natural earth atmosphere. The low-gravity environment will permit cloud expansion/contraction cycles extending into tens of minutes for the study of nucleation and growth of a cloud of droplets and/or ice crystals. The internal volume of the chamber is given in Figure 5-33 while a block diagram of the chamber associated equipment is given in Figure 5-34. The equipment requirements for the expansion chamber are very similar to the requirements of the SDI, the major addition being the expansion controller subassembly requirements for the expansion chamber. A significant dimensional change also exists and is permitted because the expansion chamber does not have the geometric restriction imposed by water diffusion between two walls as in the SDI chamber.

Weight, power, and volume is given by assembly on Table 5-16.

PORT CONFIGURATION

Y ACOUSTIC DETECTION

Z ACOUSTIC SOURCE AND DETECTION

AEROSOL INJECTION

LIGHT TRAP

X ACOUSTIC SOURCE

SCATTEROMETER SCAN PATH

DROPLET INJECTION

LIGHT SOURCE

Y ACOUSTIC SOURCE

45°

45°

LIGHT TRAP

OPTICAL HEATING

X ACOUSTIC DETECTION

LIGHT SOURCE/ IMAGE DETECTION

IMAGE DETECTION

ALL WALLS

HEAT PIPES

THERMO ELECTRIC MODULE

HEAT EXCHANGER

SPRINGS

COOLANT RETURN

COOLANT DISTRIBUTOR MANIFOLD

INSULATION

OUTER SHELL

COOLANT FLUID INLET

INTERNAL VOLUME

45 CM

30 CM DIA

OPTICAL VIEWPORTS

OUTER WALL

OPTICAL GRADE PLATES

INSULATION

ANTI FOG SURFACE

EVACUATED THERMAL BARRIER

Figure 5-33. Expansion Chamber
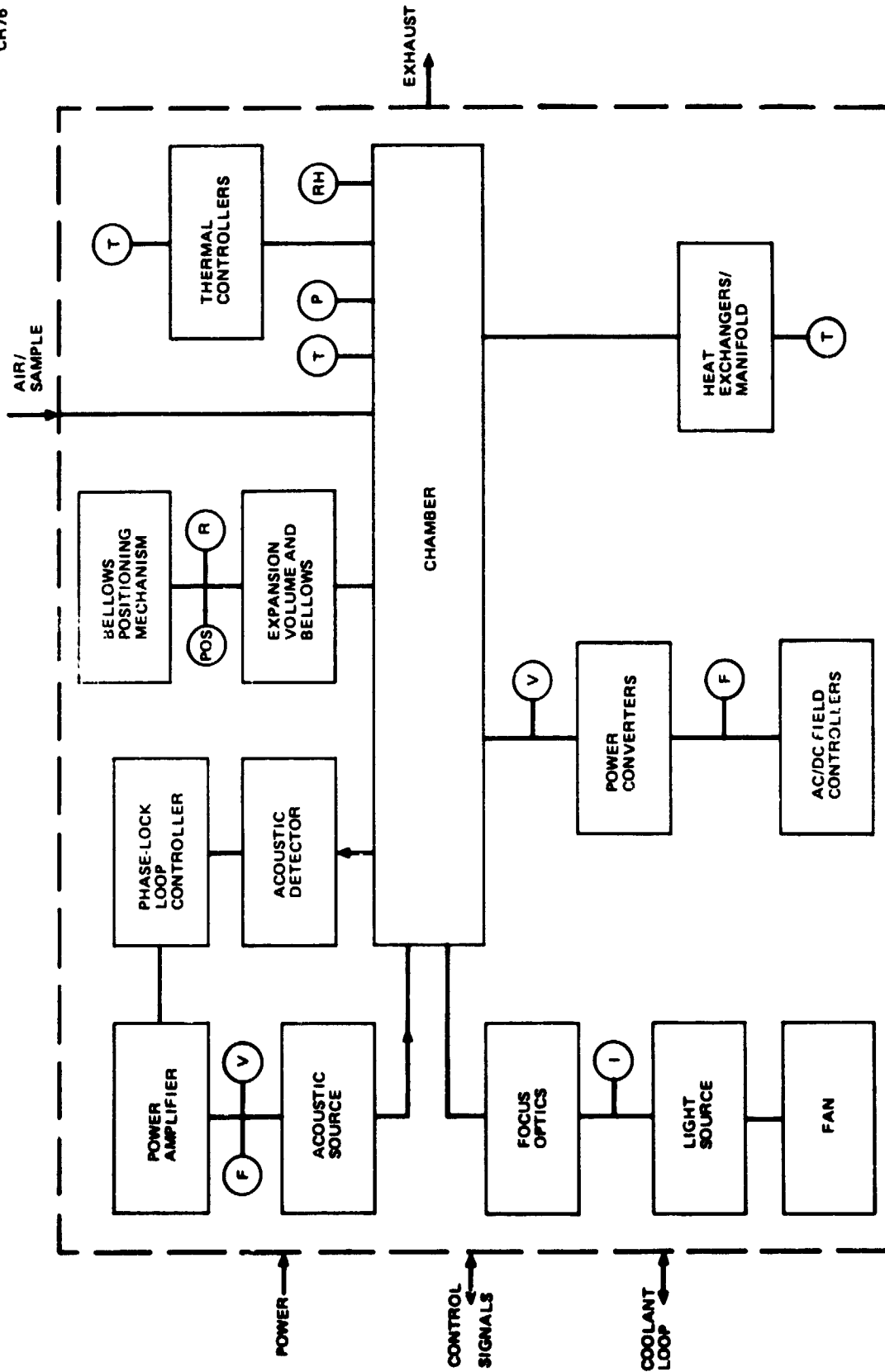
Figure 5-34. Expansion Chamber

Table 5-16
EXPANSION CHAMBER FEATURES BY ASSEMBLY

Assemblies	Weight (kg)	Volume (m³)	Power Maximum Operating (watts)	Power Nominal Operating (watts)	% Usage Experiment Time	8-Hr Average Power (watts)
Chamber Subassembly	30.22	0.079	-			
Electric Field Subassembly	9.225	0.015	40	10	5	0.5
Optical Conditioning Subassembly	4.53	0.01	750	150	5	7.5
Acoustical Subassembly	2.26	0.0014	80	20	10	2.0
Expansion Controller	51	0.2	20	20	25	5.0
Scatterometer Interface	2.27	0.0014	10	10	10	1.0
Thermal Controller	0.91	0.0003	500	100	50	50
Instrumentation and Displays	1.0	0.001	5.0	5	60	3.0
Totals	101.41	0.31	1,405	315		69

5.5.4.1 Chamber Wall Subassembly

All six walls are constructed of modular units as the SDI top and bottom, but without the wicking surface.

5.5.4.2 Optical Ports

The orientation and function of the optical ports are indicated in Figure 5-33. The inside and outside surfaces of these ports will be of high optical grade material to permit undistorted visual observation and photographic recording of the central chamber volume. Visible wavelengths will be used. The inner port surface will require antifogging, either by special coating or by controlled heating of the surface. The port unit is evacuated to minimize the thermal transport into the chamber. Antireflective coatings will also be required to maximize transmission and minimize scattering.

5.5.4.3 Equipment Mounting Ports

The general specifications are similar to those given for the SDI chamber. Mounts are required for the optical ports for (1) light source/image detection, (2) image detection, (3) light source, and (4) optical heating. Other equipment mounting ports are required (1) acoustic source/detection (six ports), (2) light traps (two), and (3) droplet injection. All mounts are to be of a universal quick-disconnect type as specified for the other chambers.

5.5.4.4 Electric Field Subassembly

This subassembly will provide an electric field within which interactions between combinations of droplets and ice crystals can be studied. The specifications are similar to those given in the SDI chamber.

5.5.4.5 Optical Conditioning Subassembly

This subassembly as used in this chamber provides remote heating of droplet or ice crystals within the chamber. This heating is accomplished by focusing IR energy onto the appropriate objects. The basic specifications are similar to those given in the SDI chamber.

5.5.4.6 Acoustical Subassembly

This subassembly provides motion and orientation control of droplets/ice crystals within the chamber. Appropriate sensor feedback is provided so that

the field energy is negligible until the constrained object moves beyond
prescribed boundaries. Some of the experiments require exact orientation
cont ol of an ice crystal. In these cases, the acoustic field will be required
on a more continuous basis but at a level which is four or five decades below
the equivalent field that would be required in a terrestrial laboratory for the
same objective. These low levels of acoustic field will not appreciably affect
those particular experiments for which the field will be required. Three axis
controls will be required. Physical configuration is illustrated in Figure 5-33.

5.5.4.7 Expansion Controller Subassembly

The expansion chamber requires a five to one expansion ratio to simulate
natural atmospheric processes. This expansion capability is provided by a
separate chamber/bellows unit classified as the expansion controller sub-
assembly. Positive displacement drive for the expansion assembly provides
controlled expansion/compression at controlled rates and for multiple cycles.

The bellows/chamber subassembly is similar to the nuclei conditioning
chamber shown in Figure 5-33 with the total length adjusted to give the
desired expansion volume. The general description of this bellows/chamber
is found under the humidification generation and control. All three units
(1) expansion controller subsystem, (2) humidification generation, and
(3) nuclei conditioning chamber have the same diameter and positioning
mechanism. The length is adjusted to satisfy the total volume requirements.

5.5.4.8 Light Trap

The light trap absorbs the chamber illumination light after this light has
passed through the chamber. The photography requires dark field illumination
with minimal background scattered light. The shape is similar to a horn of
plenty with an appropriate internal absorbing surface. Air-cooling require-
ments will be a function of the absorbed optical power. An optical port may
also be needed to satisfy thermal requirements.

5.5.4.9 Scatterometer Interface Equipment

The scan path for this detector is given in Figure 5-33. The scatterometer
detector requires sensing from several angles within the chamber, and the
liquid water content meter requires optical intensity detection from two

simultaneous angles. This interface equipment includes the sensor mountings, scan path guide rail, and stepping motor position control with optical angle encoder readout.

5.5.4.10 Thermal Controllers

Closed-loop thermal control will be used to provide the necessary temperature control of the top and bottom plates. The thermoelectric modules require dc power with less than 2 percent ac ripple component. Thermistor sensors embedded in the plate surfaces provide the feedback signal to the controllers. The top plate is controlled at a set temperature while the lower plate is slaved to the top plate with a set temperature difference. Control range is -35°C to +35°C with limited operation time below -32°C.

5.5.4.11 Instrumentation and Display Subassembly

Pressure and temperature transducers will be used to monitor the conditions within the chamber to indicate system status and performance. Figure 5-34 indicates appropriate readout locations.

5.5.5 Continuous Flow Diffusion Chamber Assembly

This chamber functions similarly to the SDL chamber in that the relative humidity within the active part of the chamber is controlled by moist, thermally controlled surfaces. The major advancement is that the continuous flow diffusion (CFD) chamber as the name implies, operates on a continuous basis. The sample is processed continuously through the chamber thus avoiding the perturbations generated by the start and stop process associated with the use of the SDL chamber. Information throughput rate is one or two decades faster with higher precision maintained over the full activated nuclei density range of 0 to 1,000/cm^3. This chamber also has been specified as a measurement instrument for nuclei characterization to be used in parallel with other chambers such as the expansion chamber. This latter procedure will provide much greater validity to the collected data.

Weight, power, and volume is given by assembly on Table 5-17.

Table 5-17

CONTINUOUS FLOW DIFFUSION CHAMBERS
FEATURES BY ASSEMBLY

Assemblies	Weight (kg)	Volume (m³)	Power Maximum Operating (watts)	Power Nominal Operating (watts)	% Usage Experiment Time	8-Hr Average Power (watts)
Chamber Subassembly	19.25	0.051	-			
Heat Exchanger	2.27	0.014	20	10	60	6
Thermal Controller	1.81	0.006	300	100	60	60
Instrumentation and Displays	2.0	0.002	5	5	70	3.5
Totals	25.33	0.073	325	115		69.5

5.5.5.1 Chamber Plate Subassembly

The two moist, thermally controlled plates of this chamber have similar thermal requirements as for the SDL plates. Figure 5-35 illustrates the present plate and chamber configuration. The major difference from the other chambers is that a heat pipe extension has been added to the plate so that the thermal energy can be rejected in a more convenient location.

5.5.5.2 Optical Ports

The orientation and function of the three optical ports are indicated in Figure 5-35. The inside and outside surfaces of these ports will be of high optical grade material to permit undistorted visual observation and photographic recording of the central chamber volume. Visible wavelengths will be used. The inner port surface will require antifogging, either by special coating or by controlled heating of the surface. The port unit is evacuated to minimize the thermal transport into the chamber. Antireflective coatings will also be required to maximize transmission and minimize scattering.

5.5.5.3 Optical Ports

Figure 5-35 illustrates the simple observation port which provides visual access to the active area between the two thermally controlled plates during operation. The inside and outside surfaces of these ports will be of high optical grade material to permit undistorted visual observation and photographic recording of the central chamber volume. Visible wavelengths will be used. The inner port surface will require antifogging, either by special coating or by controlled heating of the surface. The port unit is evacuated to minimize the thermal transport into the chamber. Antireflective coatings will also be required to maximize transmission and minimize scattering.

5.5.5.4 Water Wicking Surfaces

The top and bottom walls will be covered with a fine-mesh screen material or equivalent capillary material to provide two moist surfaces. These wet surfaces provide the water source for controlling the chamber relative humidity. The fluid surfaces are less than 0.3 mm thick and are in intimate contact with the heat pipe wall surfaces. Water is supplied to one part of each surface and the capillary action of the surface ensures uniform
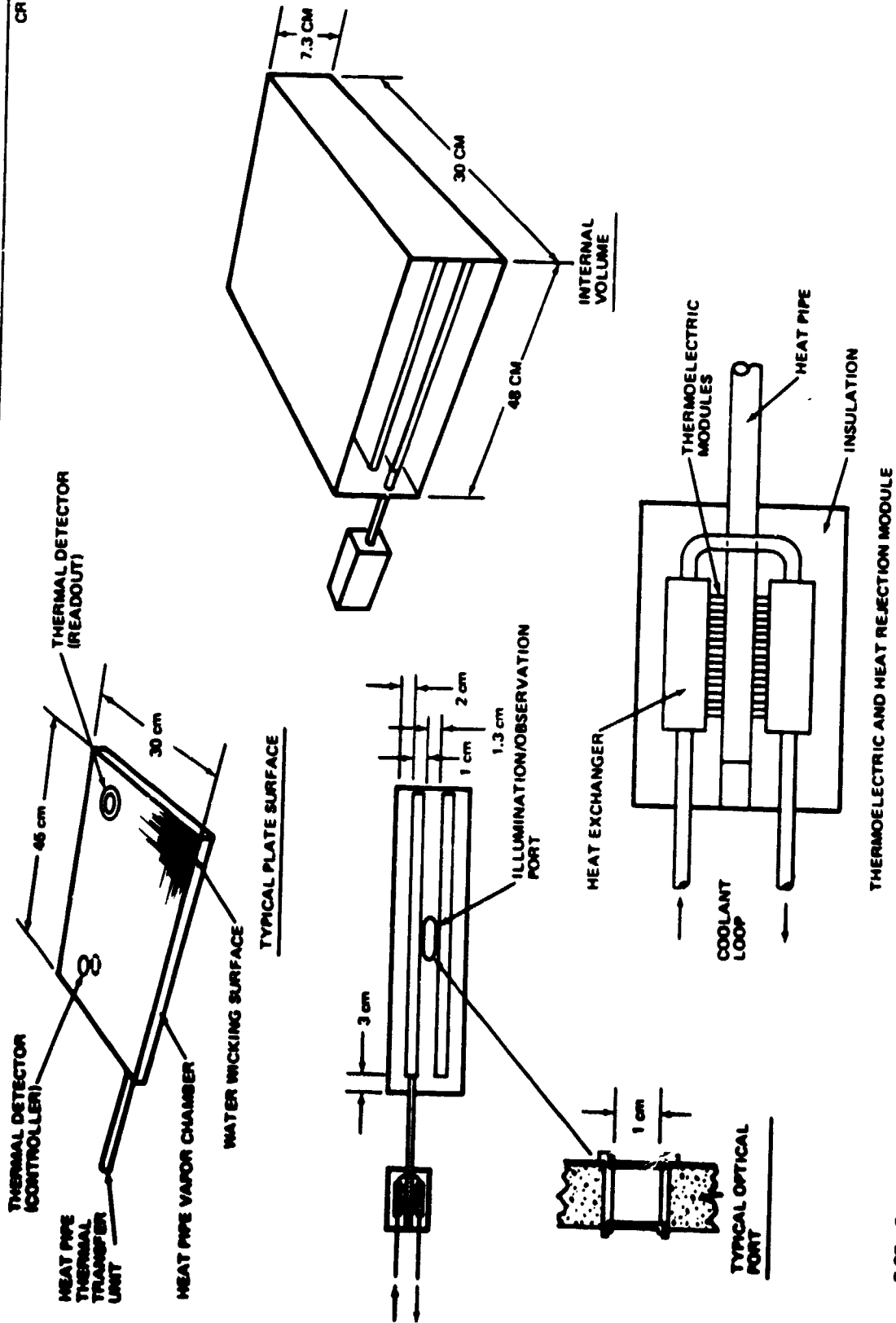
Figure B-36. Continuous Flow Diffusion Chamber

and total coverage of this surface. This chamber will require a continuous water input and output to the water wicking surface.

5.5.5.5 Chamber Wall Subassembly

The chamber wall will be similar to the side walls of the SDL and SDI walls. Insulation is required for the temperature operating range of 0°C to +35°C. The inner surface of this wall must be of controlled thermal conductivity to provide a linear thermal gradient down the wall between the plates to match the air thermal gradient of the adjacent active region.

5.5.5.6 Carrier Air Subassembly

The carrier air dewpoint is to be at least 20°C below the operating temperature of chamber to avoid supersaturation transients. This subassembly provides clean, controlled-flow air to the chamber. This air flow is so arranged as to confine the aerosol sample to a specific 3-mm region half way between the two plate surfaces. Thus the nuclei are activated in a uniform and well-defined environment. Figure 5-36 indicates the carrier air input. The flow for the carrier air through the chamber is variable between 0 and 50 cm^3/sec. Control to 1 percent or better is required. The remaining portion of the 50 cm^3/sec which does not pass through the chamber is diverted and injected just past the optical detector. Thus the carrier total flow remains a constant and ensures uniform operation of the detector recirculating pump.

5.5.5.7 Sheath Air Subassembly

This air is thermally controlled and used to ensure sample integrity while the sample is transferred from the CFD chamber to the optical particle counter. The recycling of this air also ensures that the relative humidity of the sheath air is close to the sample and carrier air thus minimizing and sample change due to evaporation. Figure 5-36 indicates the sheath air flow path and conditioning.

5.5.5.8 Thermal Controllers

The thermal control range is 0°C to 35°C. Three units are required. The top plate is controlled at a given set point. The bottom plate is slave controlled at a temperature difference below the top plate temperature, while the sheath air temperature is slave controlled to the top plate temperature.
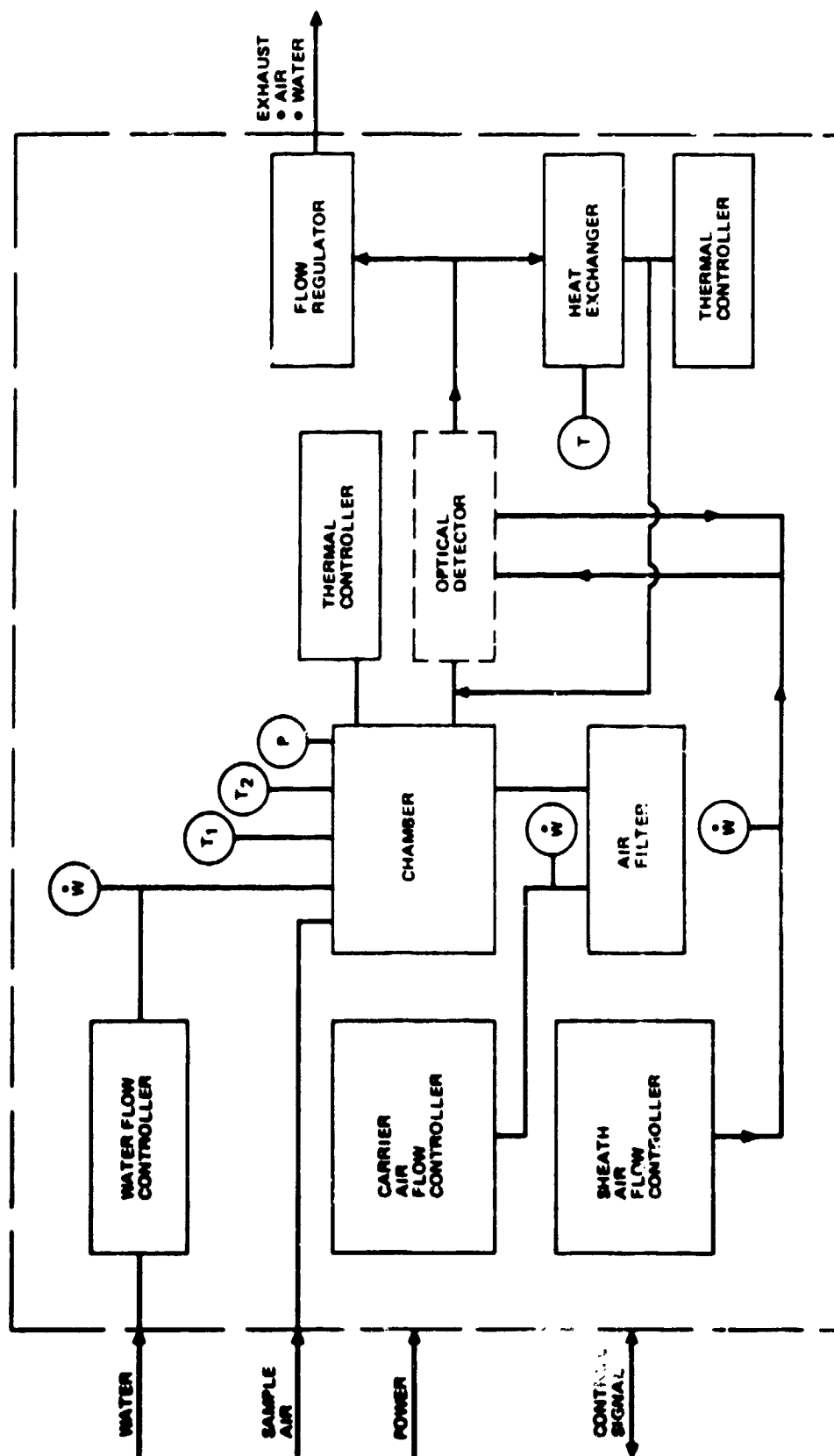
Figure 5.36. Continuous Flow Diffusion Chamber

5.5.5.9 Instrumentation and Display Subassembly

Pressure temperature transducers are used to monitor the chamber status and performance. Figure 5-36 indicates the appropriate readout locations.

5.5.6 Earth Simulation Chamber Assembly

The assembly will simulate certain aspects of planetary and solar convection with its attendant differential rotation. The experiment will consist of a differentially heated rotating spherical annulus of fluid which possesses, in effect, a radial gravity field. The radial gravity field can be modeled with radial electric fields. The experiment, in its simplest form, is designed to incorporate the major constraints of radial gravity, rotation, and spherical geometry present in the thermal convection zones of the sun, the earth's core, and the atmospheres of Jupiter and Saturn. The first two of these are thought to be characterized by isotropic heating. That is, the heat flux through the fluid is roughly independent of latitude and longitude. In the laboratory this corresponds to thermal driving which is uniform on spherical bounding surfaces. With minor changes, heating with an equator to pole differential similar to that driving the earth's atmosphere and the oceanic thermohaline circulations can be imposed.

Configuration details are given in Figure 5-37 with a block diagram of related elements shown in Figure 5-38.

Weight, power, and volume is given by assembly on Table 5-18.

5.5.6.1 Earth Simulation

This spherical model simulates general planetary atmospheric motion under simulated radial gravity gradients including rotation and thermal heating. Certain aspects of ocean circulations can also be approached. The model is defined as two concentric spheres separated by a layer of high dielectric fluid. An electric field applied between the two spheres provides the simulated gravity conditions while differential heating provides the thermal device. These variables are combined with various rates of rotation.
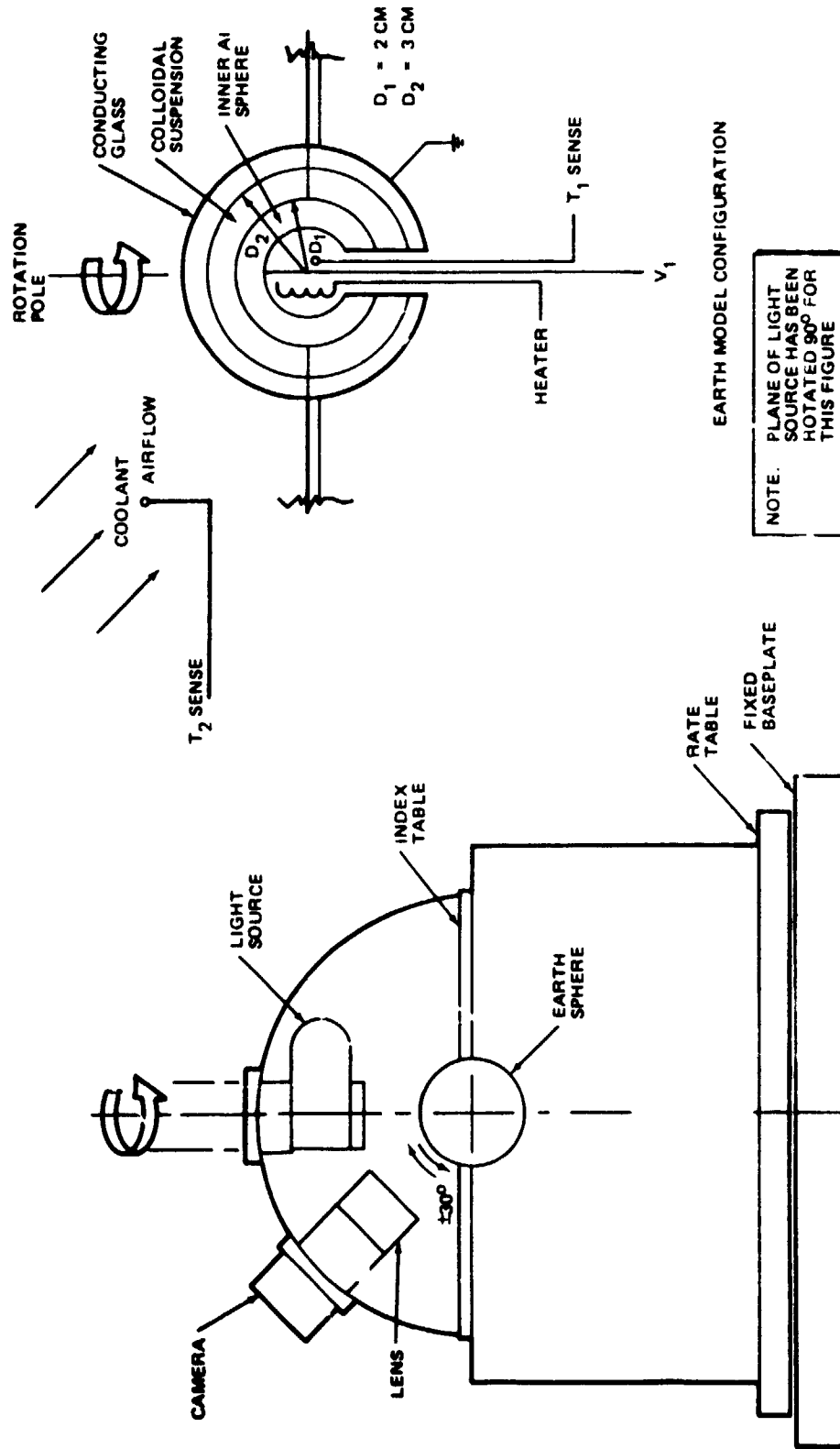
Figure 5-37. Earth Simulation Chamber
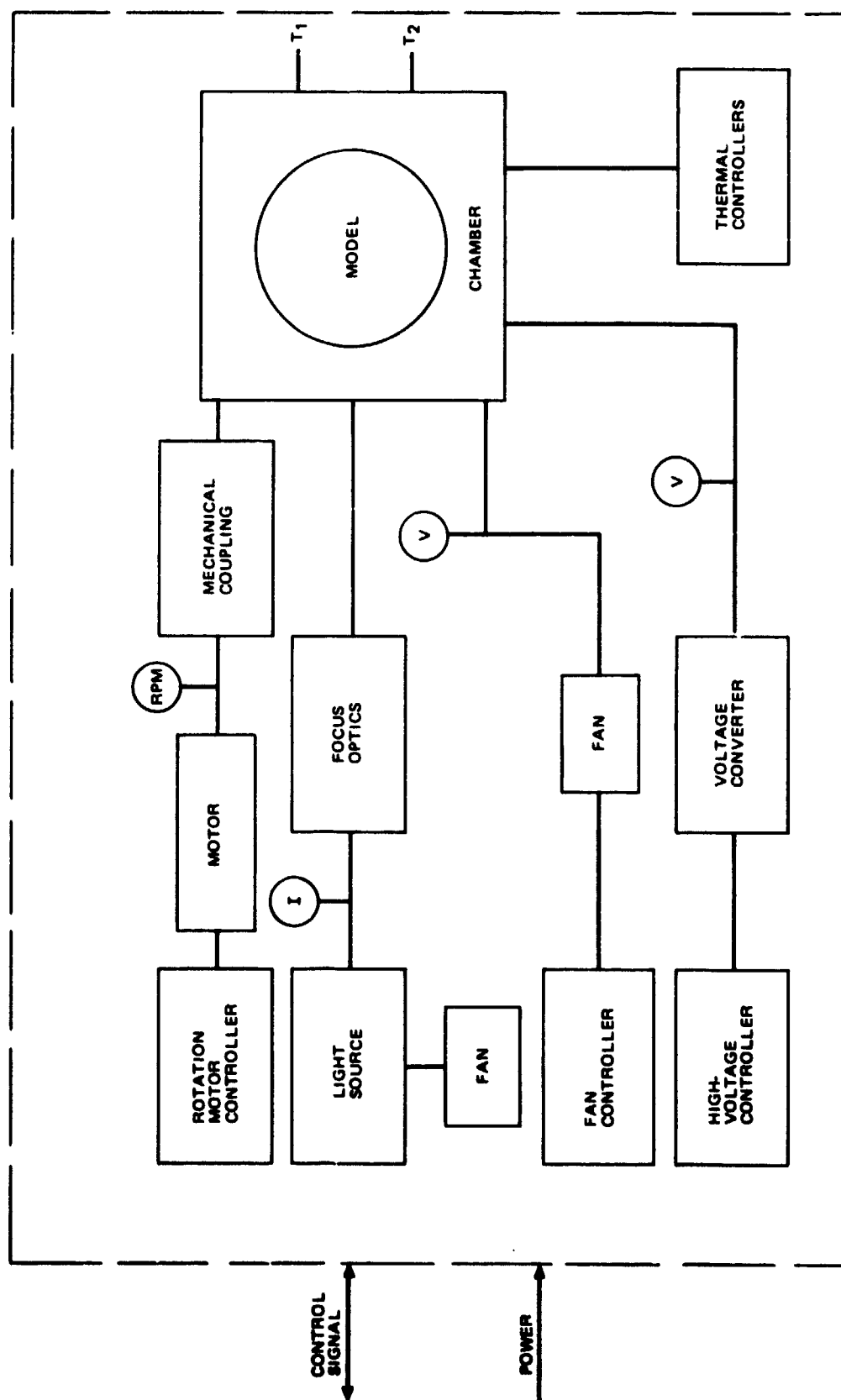
Figure 5-38. Earth Simulation Chamber

Table 5-18

EARTH SIMULATION CHAMBER
FEATURES BY ASSEMBLY

Assemblies	Weight (kg)	Volume (m³)	Power Maximum Operating (watts)	Power Nominal Operating (watts)	% Usage Experiment Time	8-Hr Average Power (watts)
Earth Simulation Model	1.36	0.01	-			
Rotating Subassembly	9.07	0.02	10	10	50	5
High Voltage Subassembly	9.0	0.017	40	20	80	16
Optical Mounting Subassembly Subassembly	2.27	0.015	-			
Thermal Controller	1.82	0.0006	200	50	80	40
Instrumentation and Displays	1.0	0.001	5	5	80	4
Total	24.52	0.064	255	85		65

The outer sphere is transparent in the visible region with an electrically conductive inner surface. Only the upper hemisphere will be used for visual purposes, therefore permitting the lower hemisphere to be constructed of metal rather than of a transparent material. The optical properties of the upper hemisphere must be of sufficient uniformity to permit direct photography of the underlying colloidal suspension. The inner sphere is electrically and thermally conductive. An electrical heater, high-voltage connection, and temperature sensor are attached to the inner cavity of the sphere.

The dielectric fluid contains suspended particles which provide a visual tag for the fluid circulation. These particles must be of several micrometers in size for photographic data, while the laser anemometer instrument could operate with submicrometer particles. A dielectric strength is required to permit upwards of 20 kv/cm electric field application with the appropriate tagging materials suspended.

5.5.6.2 High-Voltage Subassembly

A high-voltage ac electric field is applied between the inner and outer spheres across the dielectric fluid. This electric field provides the radial gravity simulation.

5.5.6.3 Optical Components Mounting Subassembly

The camera and associated equipment will be mounted in a variable position to view various angles as indicated in Figure 5-37. The angular position will be a manual adjustment.

5.5.6.4 Thermal Controllers

This unit will control the temperature of the inner and outer sphere for a temperature difference of 10°C at a heat load of about 10 watts.

5.5.6.5 Instrumentation and Display Subassembly

Transducers will provide temperatures and voltages for controlling and monitoring the model performance.

5. 5. 7 Nuclei Conditioning Assembly

This assembly is utilized to store and condition nuclei for various experiments.
The volume will provide an aerosol sample for approximately three operational
hours under most experimental conditions.   The aerosol conditioning includes
coagu'ation and diffusion battery preconditioning which shape the initial nuclei
size distribution.   Within the chamber, turbulent aerosol interaction is pro-
vided by the acoustical subassembly.   The UV light source permits photo-
chemical processes to take place while the fan provides homogeneous mixing
of nuclei sample and air for dilution purposes.   The configuration information
is provided in **Figure 5-39** while a block diagram of the related subassemblies
is given in **Figure 5-40.**

Weight, power, and volume is given by assembly on Table 5-19.

5. 5. 7. 1 Chamber Subassembly

The nuclei conditioning chamber provides several conditioning elements
in addition to providing a storage and/or aging area for the aerosol.   Positive

CR76
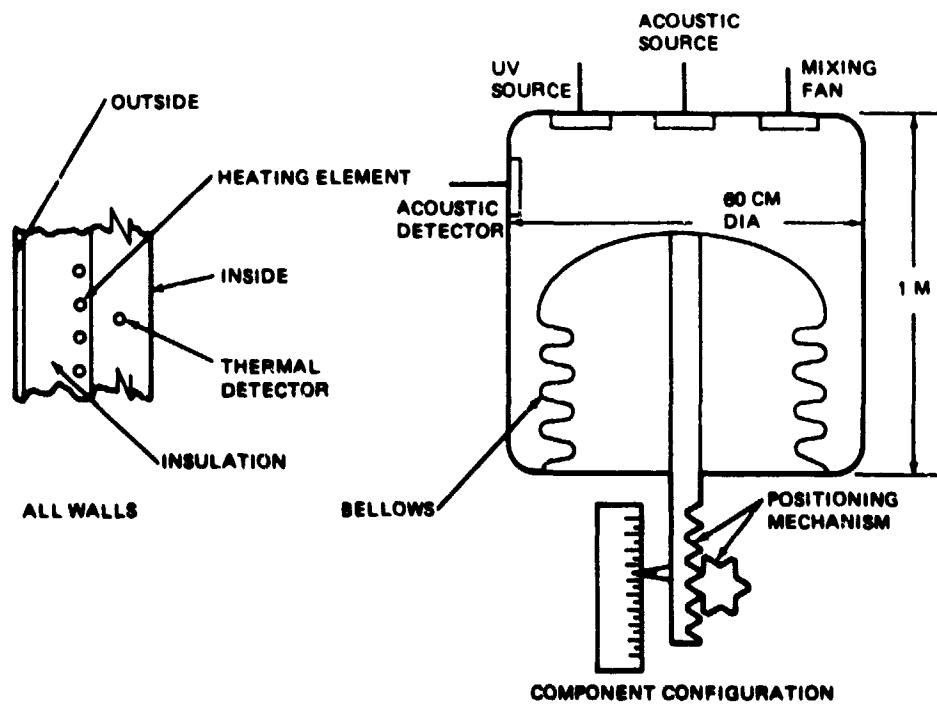
Figure 5-39. Nuclei Conditioning Chamber
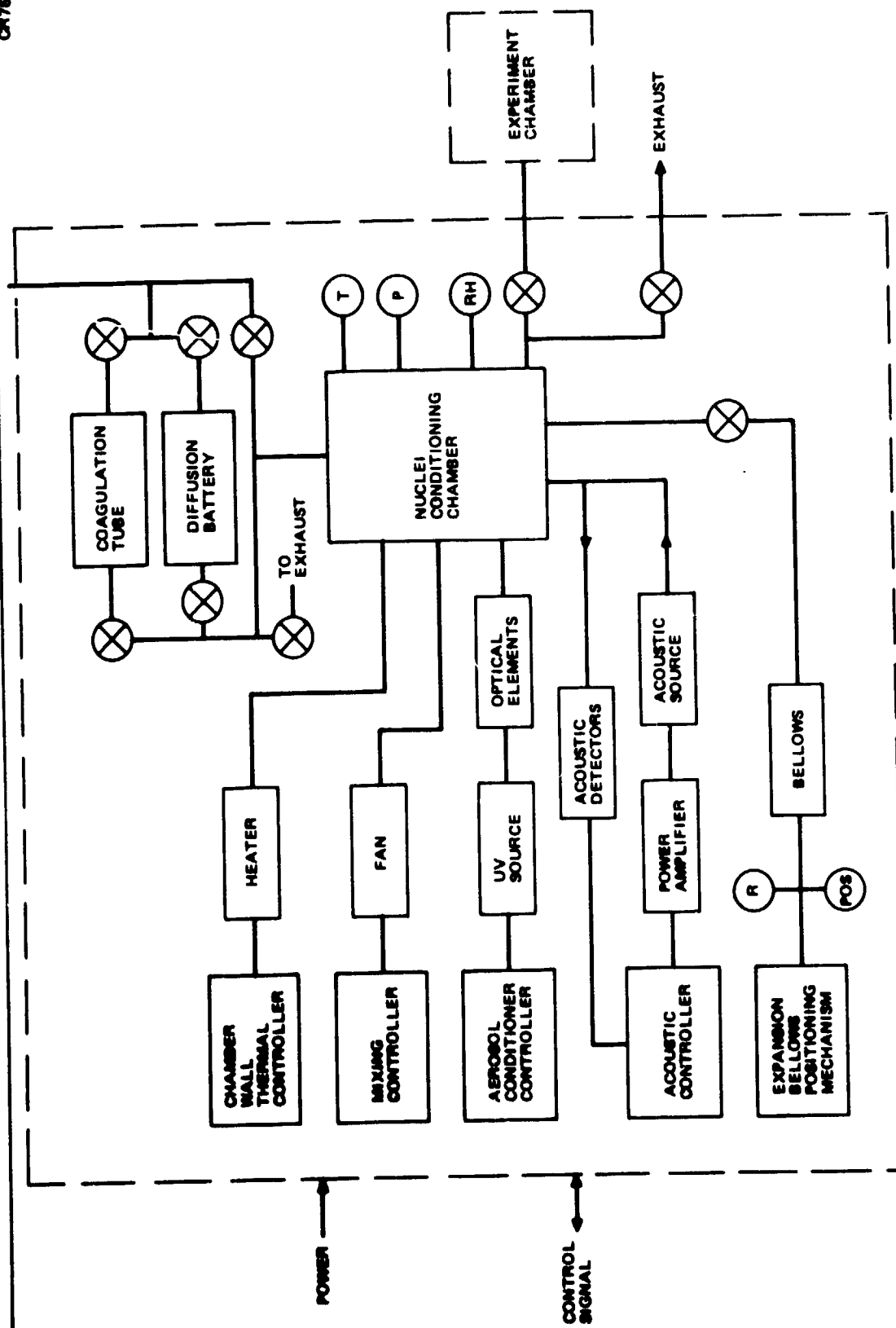
Figure 5-40. Nuclei Conditioning Chamber

Table 5-19

NUCLEI CONDITIONING CHAMBER
FEATURES BY ASSEMBLY

Assemblies	Weight (kg)	Volume (m³)	Power Maximum Operating (watts)	Power Nominal Operating (watts)	% Usage Experiment Time	8-Hr Average Power (watts)
Chamber Subassembly	81.8	0.304	-	-	-	-
Aerosol Conditioning	4.53	Included	150	60	50	30
Acoustical Subassembly	0.75	0.0005	30	10	80	8
Thermal Controller	0.91	0.0003	150	20	80	16
Instrumentation and Displays	1.0	0.001	5	5	90	4.5
Total	89.0	0.306	335	95		58.5

displacement is utilized to meter the aerosol to other appropriate assemblies. The chamber configuration is similar to the chamber used for humidification. The bellows and diameter are kept the same with an adjustment in total length to satisfy the aerosol storage volume as indicated in Figure 5-39. A heater is provided to maintain a constant and controllable elevated temperature above the working environment. Temperature range from ambient to 35°C. Insulation is provided to ensure the required isothermal conditions for the chamber. The chamber temperature uniformity must be better than 0.1°C. A light source provides optical energy for photochemical processes for smog formation studies. The duration and intensity of the exposure will be controlled. A fan assures homogeneous mixing of the initial aerosol.

5.5.7.2 Acoustical Subassembly

This subassembly provides a controlled turbulent environment to satisfy the aging and aerosol interaction requirements of some of the experiments. This procedure provides a very controlled amount of interaction which is not possible in a terrestrial laboratory because of the uncontrolled gravity-driven convection.

5.5.7.3 Nuclei Preconditioner Subassembly

Some of the aerosol sources provide nuclei sizes which must be modified to satisfy experiment requirements. A coagulation tube is provided. This is a small-diameter tube which provides time for the coagulation of the smaller nuclei to form larger nuclei before dilution and storage are initiated. The tube length, diameter, and flow rate determine the degree of coagulation for given aerosol specifications. Also included is a diffusion battery. This unit is an arrangement of very small passages which enhance the diffusion of smaller nuclei to surfaces. The result is a narrower nuclei distribution by elimination of the smaller nuclei. Nuclepore filters with pore size between 0.5 and 10 μm are used for this purpose. Flow rate and pore size determine the resulting changes in nuclei size distribution. The finite absolute pore size also places an upper limit to the nuclei size.

5.5.7.4 Valves

Valves of the ball or gate type are required to manipulate the aerosol through the preconditioning subassembly and out of the nuclei conditioning

storage chamber. Small restrictions and pressure drop units are not permitted in the aerosol manipulation lines.

5.5.7.5 Thermal Controller
The nuclei conditioning chamber will be thermally controlled between ambient (+20°C) and +35°C. The controllers are the same as specified for the other chambers. Thermal uniformity to better than 0.1°C is required.

5.5.7.6 Instrumentation and Display Subassembly
Pressure, temperature, and relative humidity transducers will be used to monitor these variables within the chamber to indicate status and perform- ance. Figure 5-40 indicates appropriate readout locations.

5.6 CONSOLE
Analysis of the CPL experiment defines volume and work station requirements that cannot be met by the standard ERNO cabinets. Investigation indicated that the ERNO cabinets can be modified and maintain their integrity to perform the interface and integration function. At this time the cost factors involved indicate a saving by performing the modifications as opposed to the design, development, fabrication, and integration of totally new cabinets. (The utilization of a 2.7-m experiment segment for the cloud physics experiment has been an assumed requirement.) The ERNO cabinets placed in a 2.7-m experiment segment would be comprised of one 0.572-m and two 1.060-m cabinets. The ERNO cabinet configuration does not meet the CPL experi- ment volume and work space/work station requirements. The most feasible utilization of ERNO cabinets in a 2.7-m segment requires modification of a 1.070-m cabinet to 1.55m and placement of a 0.572-m cabinet on either side of the stretched center cabinet.

Figure 5-41 is a composite illustration of the three modified cabinets as a final assembly of one console and summarizes the total cabinet volume available for the CPL experiment equipment. This configuration performs well for the purposes of CPL experiment as it provides a central work space with control/display and equipment storage on the right and left side of the work station. Other configurations were investigated and found not adequate in one or more areas as work station access, volume needs, cost, complexity, interface with supporting elements, and maintainability.
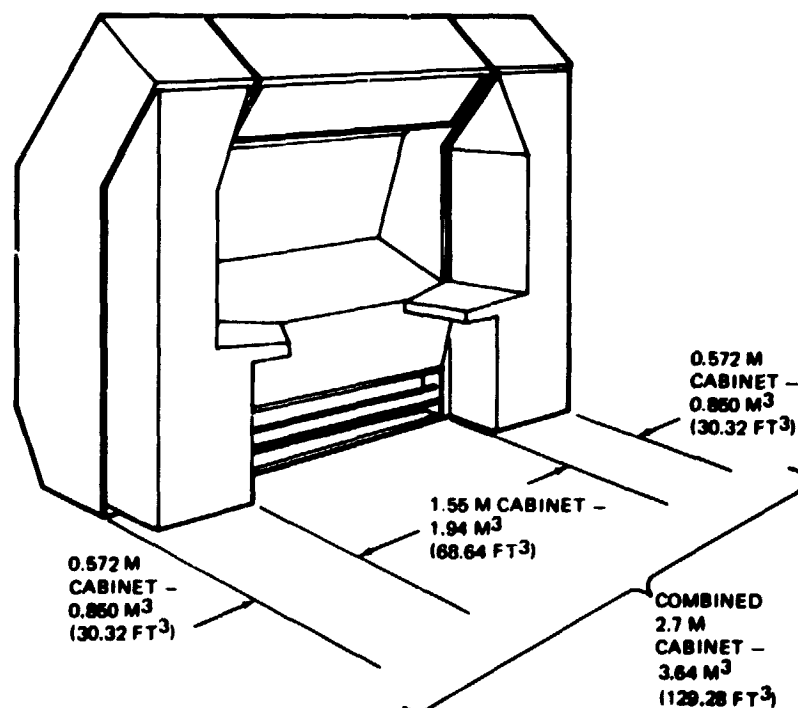
Figure 5-41. Total Cloud Physics Console/Cabinet Configuration

This subsystem consists of the following assemblies:

- A. Console support structure and subassemblies
- B. Power control and distribution
- C. Console panels and drawer subassemblies
- D. Instrumentation and displays

Weight, power, and volume is given by assembly on Table 5-20.

5.6.1 Console Support Structure and Subassembly

The basic cabinet arrangement was the subject of design and layout analysis that progressed to the model stage for verification of concept. All aspects of equipment placement, ground access, buildup, checkout, on-orbit maintenance, human experimenter visual and reach requirements, control/display access, and arrangement were considered. The final design satisfies the CPL experiment requirements and provides the 5th through 95th percentile male operator required each and visual access to the experiment work area and primary control and display functions. The center work station console has

Table 5-20

CONSOLE SUBSYSTEM
FEATURES BY ASSEMBLY

Assemblies	Weight (kg)	Volume (m³)	% Usage of Experiment Time	Maximum Operating Power	8-Hr Average Power
Console Support Structure	148	3. 64	-	-	-
Power Control and Distribution	24. 68	0. 0133	-	-	-
Overhead Storage	*56	0. 83	-	-	-
Instrumentation/Displays	5. 5	-	-	-	-
Totals by Experiment Classes	1. 78. 18	3. 64	-	-	-

*Note: Overhead storage is not required.

an increased working depth and a work surface sloped at a 15-degree angle.
The 15-degree angle will best accommodate the zero-g anthropometric work
position achieved by an experimenter in a space environment. Suitable
hand-holds and camera mounts will allow positioning of the observer or
camera so that the chamber and the display area can be viewed conveniently.

Structural modifications are required to both sides of each of the three ERNO
cabinets. Additional modification is required of the center work station
cabinet to extend the width to 1.55m from the original 1.060-m width.
Figure 5-42 indicates the structure of the ERNO cabinets after modification
work has been performed. The structural members modified or added are
shown in heavy line. The members deleted are shown in dashed line.

5.6.2 Power Control and Distribution

A universal type power distribution network is required for the CPL experi-
ment to achieve a high degree of flexibility for performing various types of
experiment and recording of data. A universal network consists of all the
circuits required to transmit the various types of power and to provide each
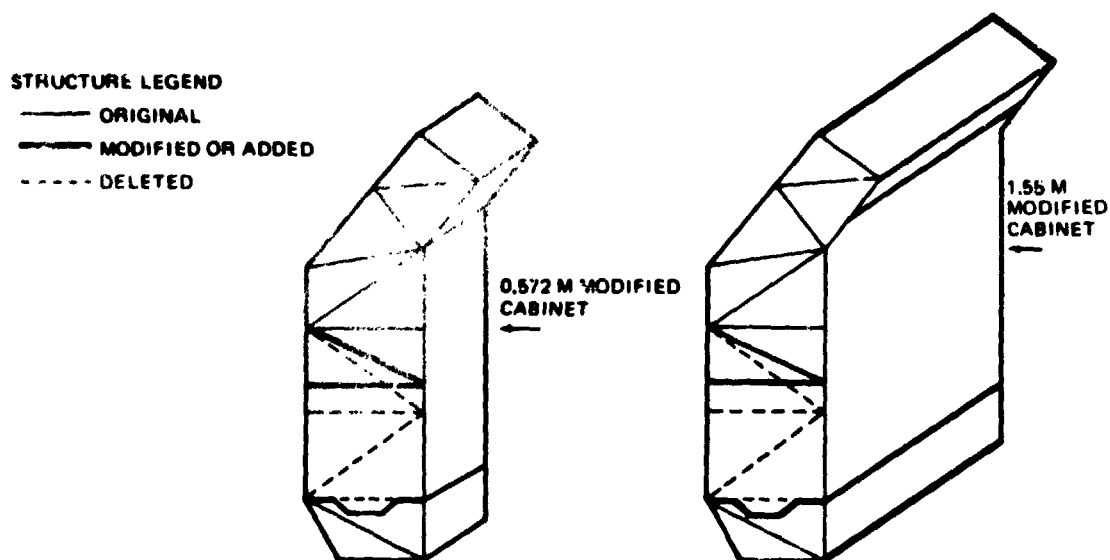
Figure 5-42. Structure Modification — 1.55-M and 0.572-M Cabinets

circuit with multiple receptacles for connection of experiment equipment and support/instrumentation packages. The electrical power conditioning and distribution subsystem (EPCDS) receives its primary power from the Shuttle Orbiter via the Spacelab. The baseline power is:

   A.   Unregulated 28 vdc

   B.   115/200 vac, 3 phase, 400 Hz

Utilizing the baseline power from the Spacelab and providing the necessary conditioning, the following circuits were defined for the CPL experiment:

   A.   28 vdc regulated

   B.   110/200 vac, 3 phase, 400 Hz

   C.   110 vac, 1 phase, 400 Hz

   D.   110 vac, 1 phase, 60 Hz

Figure 5-43 shows the envisioned power control and distribution network. The nominal power rating of each main circuit is 800W and the current-carrying capacity was sized for a peak rating of 150 percent. The current-carrying rating was based on specification MIL-W-5088.

LENGTH .;r WIRE HARNESS FROM POWER DISTRIBUTION
BOX TO RECEPTACLE ≈ 10M
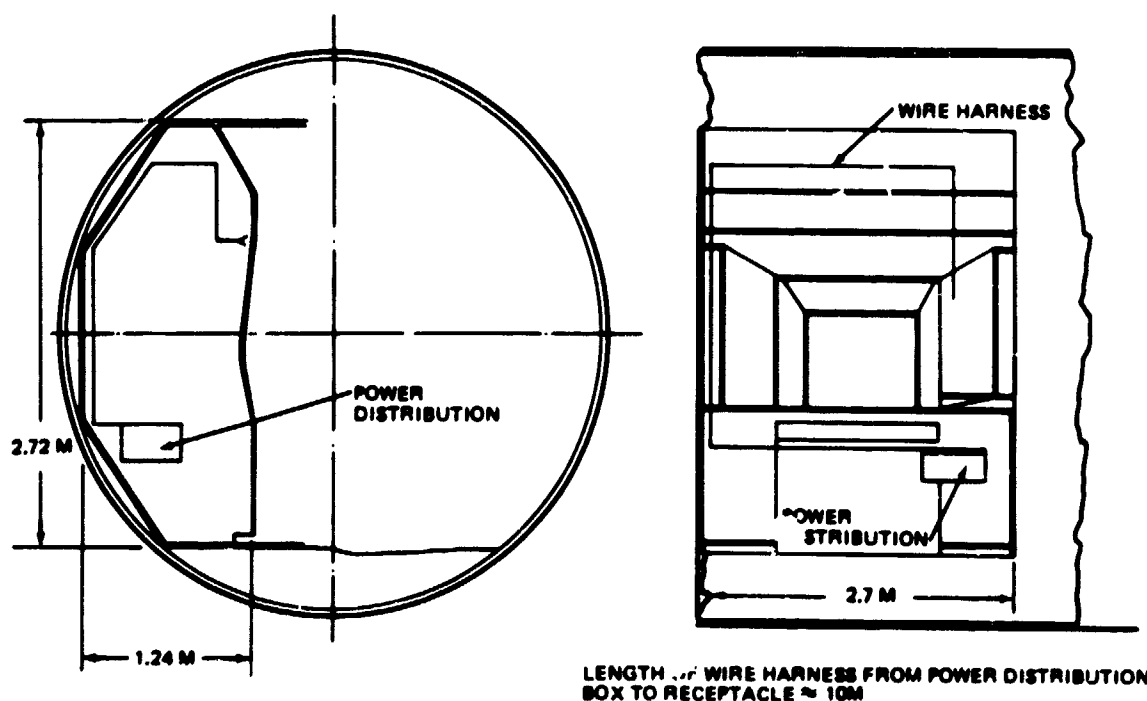
Figure 5-43. Power Distribution

5.6.2.1 28-VDC Regulated Circuit

The 28-vdc circuit is shown in Figure 5-44 and consists of the converter, a
400W and 600W line, circuit breakers, and receptacles. The converter is
1,100W which is 25 percent greater than the nominal load of 800W and is an
add-on unit. The wire size, amperage, and voltage are shown in the figure.
The 400-W line is a general-purpose line and terminates with four female
receptacles. The 600-W line is semi-dedicated to supply power to the onboard
thermoelectric cooler which may require up to 600W of power. However the
line may also be used to supply power for other functions via the two recep-
tacles when the thermoelectric cooler is not at full-power demand.

5.6.2.2 110 VAC, 3 Phase, 400 Hz and 100 VAC, 1 Phase, 400 Hz Circuits and

the 110 vac, 3 phase, 400 Hz circuit connects directly to the Spacelab power
distribution system. The 110 vac, 3 phase circuit is shown in Figure 5-45
and is a 4-wire system. The circuit consists of the wire harness, circuit
breakers, and four female receptacles. The wire size, voltage, and amperage

CR76

1,100 W DC/DC CONVERTER (ADD-ON) 28 VDC ±0.5 V

400 W 19.7 AMP

NO. 8 WIRE (23 AMP RATING) ΔV = 0.8 V LINE DROP

600 W 29.1 AMP

NO. 6 WIRE (60 AMP RATING) ΔV = 0.8 V LINE DROP

THERMOELECTRIC COOLER – SEMI-DEDICATED
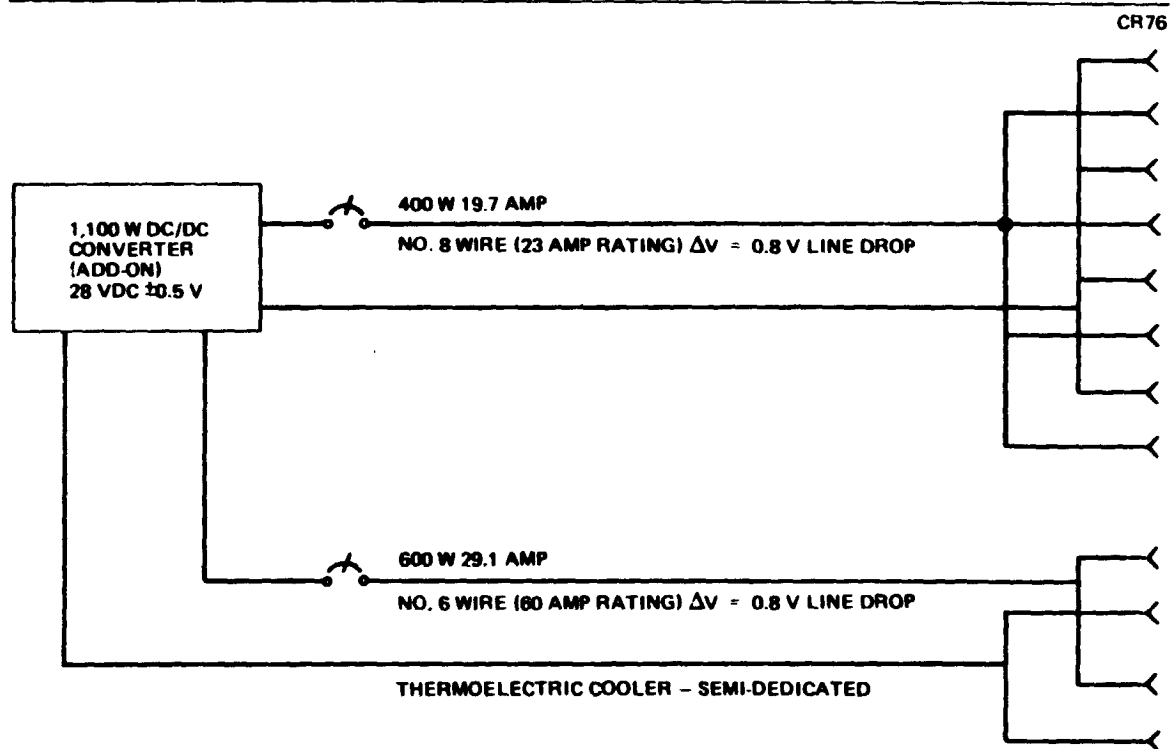
Figure 5-44. 28 VDC Regulated Circuits

CR76

800 W 7.8 AMP

110 V

NO. 14 WIRE (17 AMP RATING)

110 VAC ±10% 3 PHASE 400 Hz 4 WIRE SYS

110 V

ΔV = 1.4 V LINE DROP

110 V

4 RECEPTACLES (TYP)

110 VAC ±10% 1 PHASE 400 Hz

NO. 14 WIRE (17 AMP RATING) ΔV = 2.5 V LINE DROP

800 W 13 5 AMP

4 RECEPTACLES (TYP)
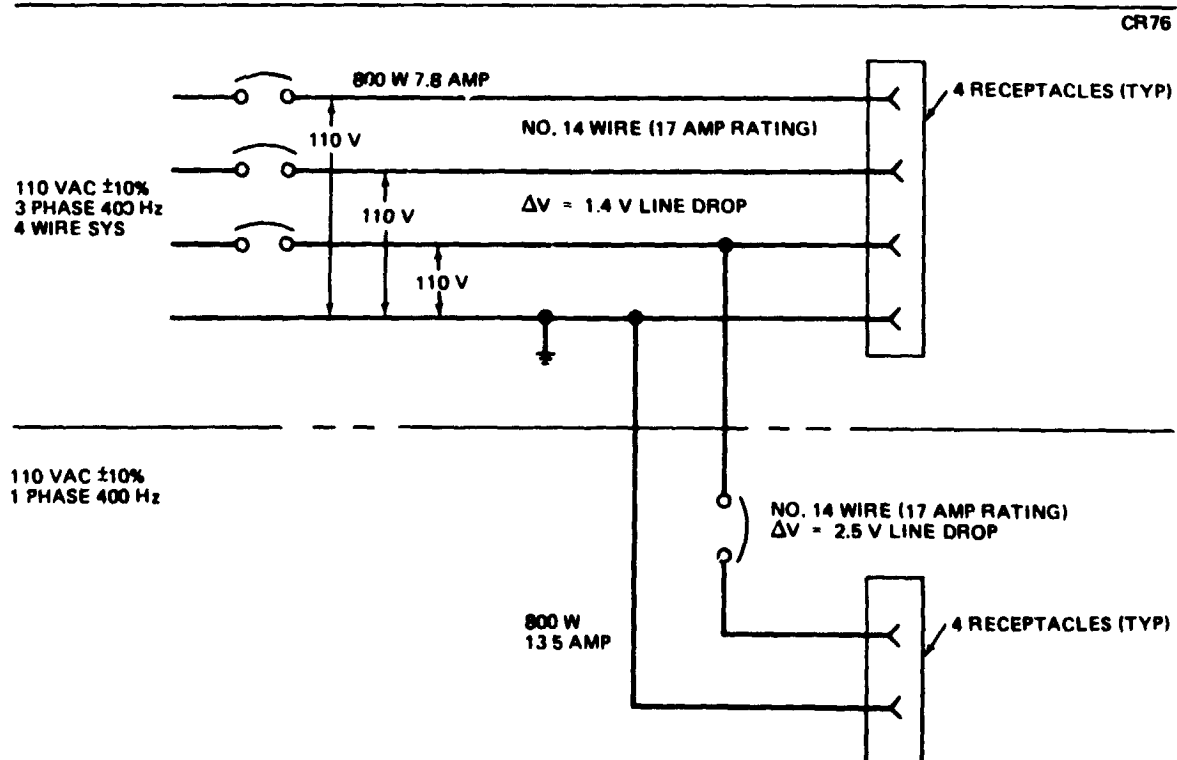
Figure 5-45. 110 VAC 3 Phase 400 Hz and 110 VAC 1 Phase 400 Hz Circuits

are shown in the figure. One line of three-phase power line is tapped to supply up to 800W of single-phase power. Based on this requirement, the 3-phase power line size was then calculated to be number 14 wire.

The 110 vac, 1 phase, 400 Hz circuit is shown in Figure 5-45 and consists of the wire harness, circuit breaker, and four female receptacles. The line size, amperage, and voltage are also shown.

5.6.2.3 110 VAC, 1 Phase, 60 Hz Circuit

The 110 vac, 1 phase, 60 Hz circuit is shown in Figure 5-46 and consists of the dc/ac inverter, wire harness circuit breaker, and four female receptacles. The wire size, amperage, and voltage are shown in the figure. The inverter is rated at 1,100W which is 25 percent greater than the nominal load of 800W and is an add-on unit.

5.6.2.4 Circuit Breakers, Receptacles, and Meters

The circuit breakers used in the circuits are single-pole thermal types and meet the requirements of MIL-C-58090. The breakers are designed to carry
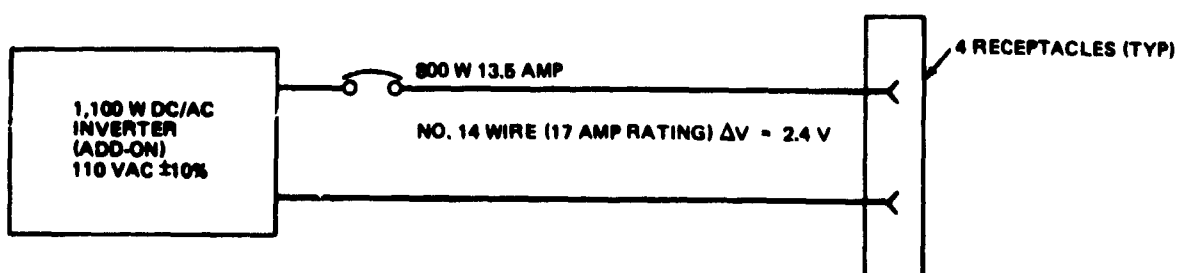
Figure 5-46. 110 VAC 1 Phase 60 Hz Circuit

115 percent of rated load indefinitely with ultimate trip at 138 percent of rated load. The trip time at 200 percent of load is approximately 25 seconds.

The receptacles investigated are of the Amphenol type, meeting the military MS specification. The meters consists of voltmeters, wattmeters, and ammeters consistent with typical aerospace/aircraft standards.

5.6.3 Console Panels and Drawer Subassembly

Figure 5-47 defines the volume that the equipment racks of the 0.572-m cabinet are capable of containing. The volume is broken down into small segments to accommodate the placement of equipment packages, instrumentation, and storage volumes. Table 5-21 identifies the dimensions of the individual volumes shown in Figure 5-47. Figure 5-48 defines the volume of the equipment racks, storage racks, and free work volume of the 1.55-m cabinet. Table 5-22 identifies the dimensions of the individual volumes shown in Figure 5-48.

Table 5-21

VOLUME/EQUIPMENT RACK (0.572m) CABINET - EXPERIMENT SEGMENT

Volume No.	Multiply by form factor	Width (in.)	Face Length (in.)	Depth (in.)	m^3	ft^3
1		17	15	18	0.075	2.65
2		17	20	24	0.132	4.73
3		17	20	18	0.10	3.55
4		17	31	24	0.207	7.35
5		17	30	19	0.159	5.60
6	0.5	17	14	14	0.037	1.35
7	0.5	10	23	18	0.034	1.2
8	0.375	7	23	18	0.017	0.63
9		10	31	18	0.091	3.22
10		7	$\frac{31}{2}$	18	0.032	1.12
Total 1 through 10					0.887	31.67
Total less volume 6					0.850	30.32

VOL 6
0.037 M³
(1.35 FT³)

VOL 5
1.59 M³
(5.60 FT³)

VOL 7
0.034 M³
(1.2 FT³)

VOL 8
0.017 M³
(0.63 FT³)

VOL 4
0.207 M³
(7.35 FT³)

VOL 9
0.091 M³
(3.22 FT³)

VOL 10
0.032 M³
(1.12 FT³)

VOL 2
0.132 M³
(4.73 FT³)

VOL 3
0.1 M³
(3.55 FT³)

TOTAL VOLUME = 1.7 M³
(60.84 FT³)

VOL 1
0.075 M³
(2.65 FT³)

VOL 6
VOL 5
VOL 7
VOL 8
VOL 9
VOL 10
VOL 4
VOL 3
VOL 2
WORK
SHELF
VOL 1
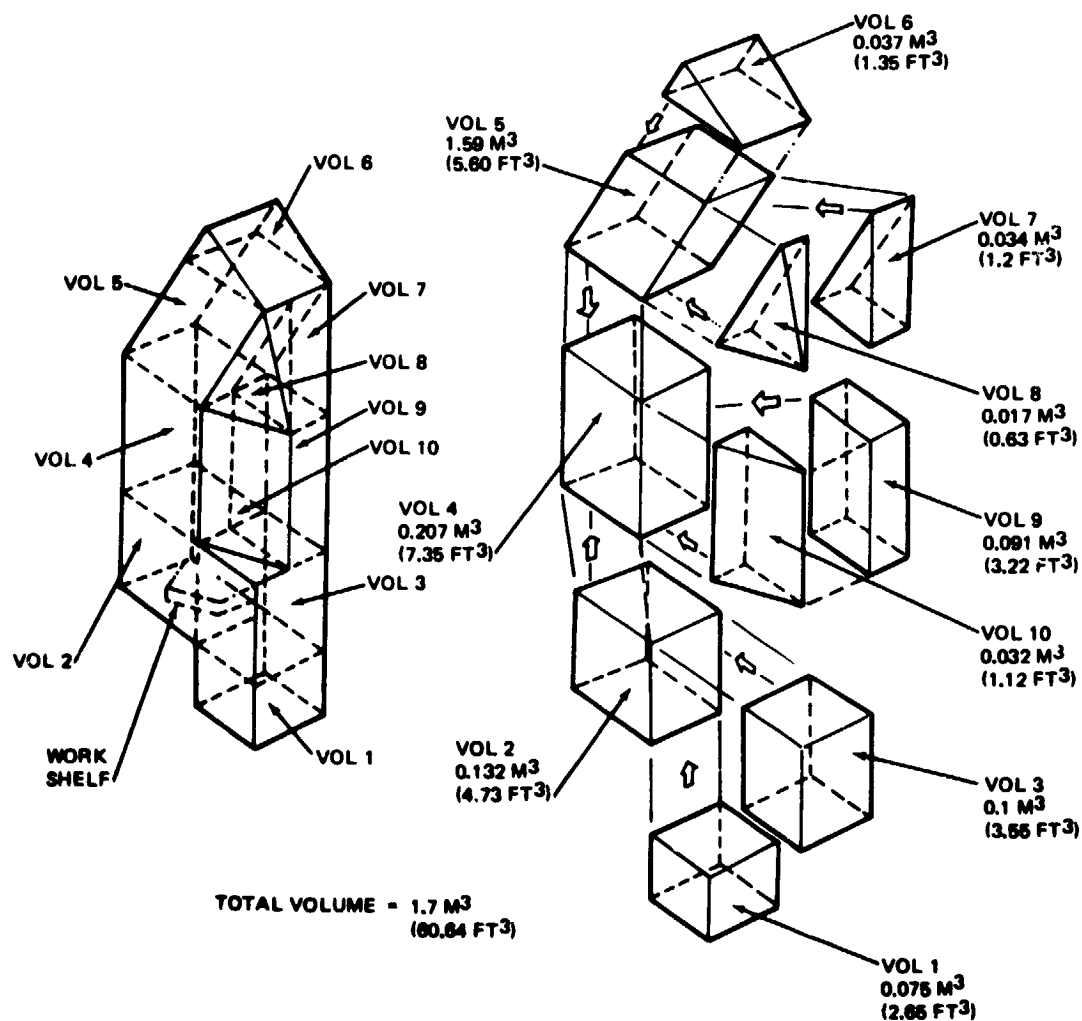
Figure 5-47. Volume Breakdown of 0.572-M Cabinet

VOL 4
0.329 M^3
(11.6 FT^3)

VOL 4

VOL 3
0.19 M^3
(6.72 FT^3)

VOL 3

VOL 2

VOL 2
0.794 M^3
(28.08 FT^3)

VOL 1

VOL 1
0.627 M^3
(22.24 FT^3)

TOTAL VOLUME = 1.94 M^3
(68.64 FT^3)
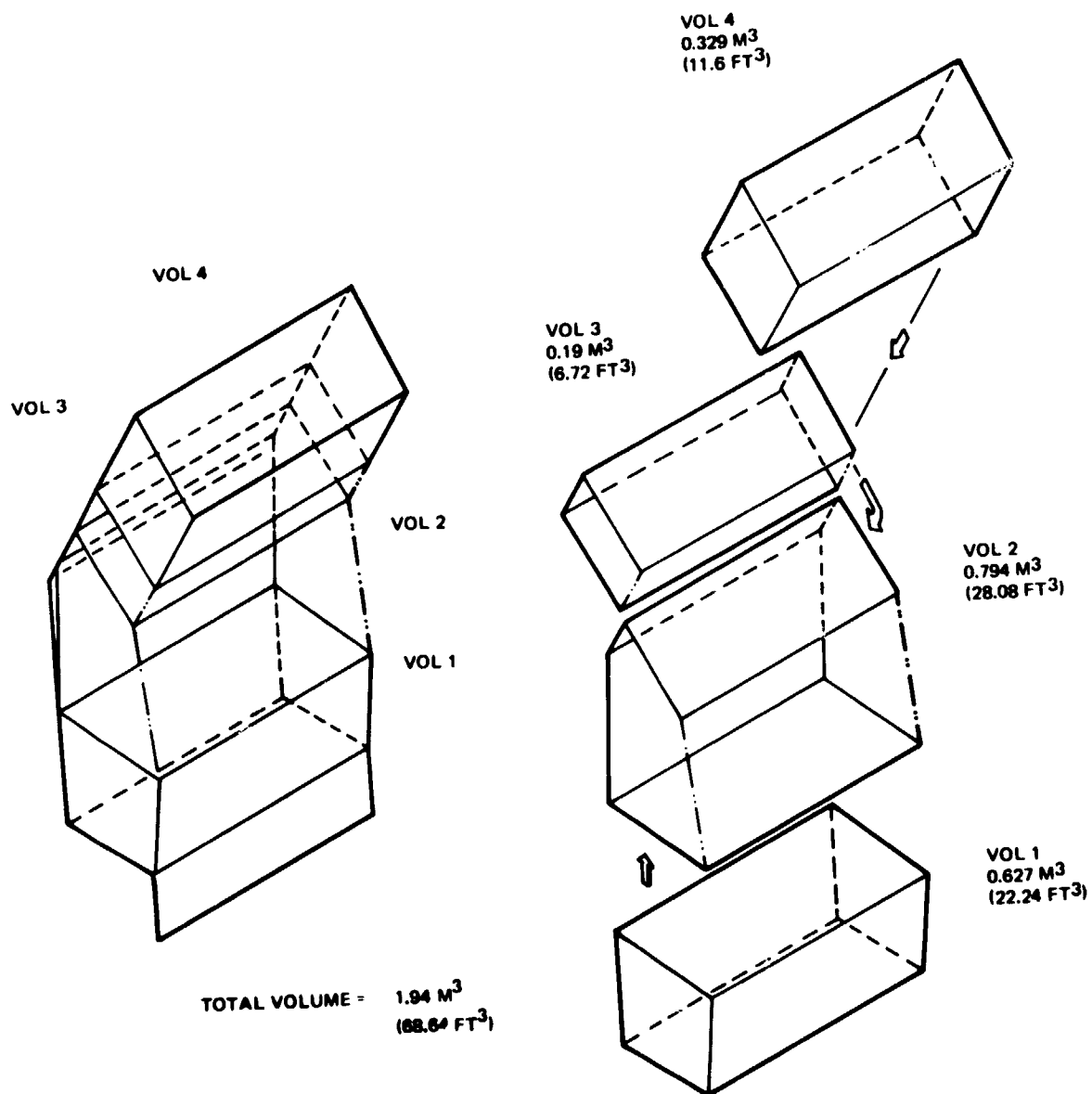
Figure 5-48. Volume Breakdown of 1.55-M Cabinet

Table 5-22

VOLUME/WORK STATION (1.56 m) CABINET -

EXPERIMENT SEGMENT

Volume No.	Width (in.)	Face Length (in.)	Depth (in.)	m^3	ft^3
1	56	25	30	0.627	22.24
2	56	30	26	0.794	28.08
3	56	11	19	0.19	6.72
4	56	19	19	0.329	11.6
Total 1 through 4				1.94	68.64

5.6.4 Instrumentation and Displays

CPL operation will be facilitated by the use of visual digital displays for temperature, pressure (relative humidity), gas flow, elapsed time, and other pertinent experiment parameters which require observation during the course of the experiments. The proper operation of other subsystems of the CPL will be displayed on the console via indicating lights. These displays and lights will be mounted on the panels of the console and arranged in logical and orderly arrays to indicate visually the actual location and function of the control within the subsystems.

5.7 OPTICAL AND IMAGING DEVICES

The five experiment cloud chambers have varying depths and require photography of objects which may be within a large variable distance from the chamber walls. This distance can vary between 3 to 23 cm. Optical access is provided by a double-walled viewing port which further increases the distance to the first lens of an observational viewing system. This variable

distance from the first lens element and the possible object position is 8 to 30 cm. A set of coupling optics next to the viewport allows a variable focal zoom to focus on the particles in the 8- to 30-cm range. The parallel light output of these optics permit a confocal stereo microscope and a film camera to view the particles at the same time through a beam splitter. The astronaut utilizing a small joystick type control can maintain focus on the particles as they shift position and can exercise a tilt and pan to move the recorded scene left or right, up or down (±15 degrees). Magnification changes can be made independently at the microscope or the film camera without affecting the focus.

One 80 to 200 mm zoom lens on the film camera and one set of zoom eyepieces for the microscope coupled with the coupling optics barrel will accommodate the photographic needs for the SDI, SDL, E, and G chambers. The earth simulation chamber has unique photographic requirements which can be met with a fixed-focus lens and motor-driven magazine on a still camera body. This camera with a normal 36-exposure magazine can also be used to photograph any specimens removed from any chamber and observed under a higher powered binocular microscope.

The CFD chamber does not require photographic recording and/or video camera monitoring. The data are obtained by a particle counter and recorded on magnetic tape.

Table 5-23 shows the subsystem equipment utilization versus experiment class.

The optical and imaging devices subsystem contains the following assemblies:

    A.   Cine camera (35mm)
    B.   Still camera (35 mm)
    C.   Microscope, trinocular
    D.   Video camera assembly
    E.   Light source
    F.   Anemometer
    G.   Stereo microscope
    H.   IR microscope
    I.   Support equipment/expendables
    J.   Displays

Table 5-23

SUBSYSTEM EQUIPMENT UTILIZATION

Optical Detection and Imaging Devices	Experiment Class																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
35-mm cine camera	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-
35-mm still camera	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	x	x	x
Stereo microscope	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-
Trinocular microscope	x	-	-	-	-	-	-	-	-	-	-	x	x	-	x	x	-	-	-	-	-
TV camera	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-
Anemometer	-	-	-	x	-	-	x	x	-	x	-	x	-	-	-	x	x	x	-	-	x
IR microscope	-	x	x	x	x	x	x	-	x	x	x	-	-	-	-	x	x	x	-	x	-
Light source	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Weight, power, and volume is given by assembly on Table 5-24 and by experiment class on Table 5-25.

5.7.1 Cine Camera (35 mm)

This is a 35-mm motion picture camera with an 80 to 200 mm zoom focus lens. The motor-driven magazine will hold up to 500 ft of film. Any speed from 0 to 100 frames per second with a binary format time word imposed on each frame will be available. The zoom lens can be motorized to permit remote changes of focal length for magnification changes. The astronaut will control the frame speed and magnification remotely. Film transport will be of the pin-registered type. The electrical requirements are 110 vac, 60 cycle. Motor drive may be modified to take the power supplied to the CPL. The larger 35-mm double frame will allow greater field coverage than the 16-mm single frame and minimum camera tilt and pan movement. The 35-mm lens focal length availability matches the coupling optics focal lengths to achieve a magnification range of 1 X to 4 X in the film.

Table 5-24

OPTICAL DETECTION AND IMAGING DEVICES SUBSYSTEM
FEATURES BY ASSEMBLY

Assemblies	Weight (kg)	Volume (m³)	Power Maximum Operating (watts)	Power Nominal Operating (watts)	% Usage Experiment Time	8-Hr Average Power (watts)
35-mm Cine Camera	4.54	0.006	280	280	4	11.2
35-mm Still Camera	1.13	0.0011	5	5	10	0.5
Stereo Microscope	2.72	0.007	0	-	-	0
Trinocular Microscope	2.95	0.007	20	20	10	2
TV Camera	5.00	0.006	30	30	40	12
Anemometer	43.09	0.036	500	500	30	150
IR Microscope	40.82	0.07	100	100	10	10
Light Source	1.36	0.0017	160	160	40	64

Table 5-25

OPTICAL DETECTION AND IMAGING DEVICES SUBSYSTEM
FEATURES BY EXPERIMENT CLASS

Experiment Class No.	Weight (kg)	Volume (m^3)	Power Maximum Operating (watts)	8-Hr Average Power (watts)
1	4.31	0.009	180	66
2	51.03	0.086	295	86
3	51.03	0.086	295	86
4	98.66	0.128	1,075	248
5	51.03	0.086	295	86
6	51.03	0.086	295	86
7	94.12	0.122	795	236
8	53.30	0.051	695	226
9	51.03	0.086	295	86
10	94.12	0.122	795	236
11	51.03	0.086	295	86
12	56.25	0.059	715	228
13	11.80	0.023	215	78
14	18.85	0.016	195	76
15	11.80	0.023	215	78
16	95.71	0.129	815	238
17	96.17	0.127	1,075	248
18	96.17	0.127	1,075	247.7
19	8.85	0.016	195	76
20	49.67	0.086	295	86
21	44.22	0.039	665	214

5.7.2 Still Camera (35 mm)

This 35-mm still camera is used for time-lapse and single-shot photography where greater than 4 frames per second is not required. In these respects, the motion picture camera can provide a backup capability. The still camera is also used to take single shots of specimens outside the chambers and viewed under the high-resolution binocular microscope. Certain of the experiments do not require much film (e.g., 2, 11, 13, and 16). The small cassettes that result permit the use of a camera smaller than a motion picture camera. A 75-mm camera was not called for here, due to the optical coupling configuration selected. The film remains standardized at double-perforated, 35-mm film for all recordings. Given a film loader, the astronaut can remove film from the motion picture reels to load the still camera cartridges, if necessary. The lens on the motion picture camera is suitable for the 35-mm camera. There will be one 55-mm, fixed-focal-length lens needed by the still camera for the requirements of the earth simulation experiment. This camera requires no coupling optics for the earth simulation experiment. Focusing will be accomplished by the astronaut through the lens in the normal way, and then the camera is left to revolve on the rate table with the experiment.

The individual double frame formats will have a binary format time word imprinted at the moment of exposure.

5.7.3 Microscope Trinocular

This unit is utilized by the astronaut to observe specimens that have been removed from the chamber. It will have a range of magnification up to 400 X. The illumination will be supplied either under or over the specimen. Optical staining accessories will be supplied for detail enhancement such as the Nomarski differential interference technique and polarization technique. One of the two illumination modules normally used on the chambers can be removed and used for this microscope. Attachments will be supplied so that still photographs can be taken by the 35-mm still camera.

5.7.4 Video Camera Assembly

The video camera is a standard unit 525-line raster on a 1-inch tube with a 4.0-MHz bandwidth. The camera with a zoom lens sees through a beam splitter in one of the illumination modules which in turn is attached to the viewport to one side of the observational viewport. With a wider angle lens at this position, the unit provides the astronaut with a view of the chamber much greater than that provided by his microscope. Using the monitor screen, he can observe droplets introduced in the chamber and see the overall trajectory as they are propelled. Since the cameras video output can be recorded on a video tape recorder, the astronaut can playback scenes of droplet trajectories on the monitor at will. The camera and monitor gives him another eye and viewing position to observe the experiment.

The 50 to 200 mm zoom lens will cover the maximum field allowed by the 7-cm clear aperture lighting port ± 12 degrees as well as permit a 1 X magnification at the maximum range of 450 mm.

5.7.5 Light Source

The housing of the light source is a copy of the illumination module developed for the Apollo-Soyuz Salt Breakup experiment by P. Layky and J. Schaefer. The module would be modified to take either the 60-watt tungsten-halogen bulb and socket or the miniature FFT-6 xenon short-arc bulb and socket. The tungsten bulb would be utilized when CW illumination is required. When both CW and strobed illumination is required, the short-arc source would be used. The short-arc power input is 12 watts average with a trigger voltage for starting of 2 to 4 kvdc.

The bulb is backed by a spherical reflector with a cold mirror coating. The light from the bulb and ..e image of the bulb is collected by the collimator lens. The collimator lens can be positioned to control the divergence of the light beam. This insures that the desired chamber volume is illuminated and the reflections from the chamber walls do not result in flare light into the film camera. The output light strikes a 45-degree mirror before entering the chamber. This mirror has a cold coating (transmissive in the IR) as does the spherical mirror.

One of the illumination modules has a beam splitter 45-degree mirror with a cold mirror coating. This is the module with provision for the video camera to mount on and look into the chamber through the 45-degree mirror. The output side of the module has provisions for light filters. These filters may be polarizers, light attenuators, or color filters depending on the photographic requirement.

The module will not have an active cooling system. The chamber will be protected from thermal radiation from the housing by means of a superinsulation pad. The thermal output spectrum of the lamp will not be reflected by the cold mirror coating on the spherical and 45-degree plane mirrors. Thus the light entering the chamber will have a spectral cutoff about 0.80-μm wavelength. The module will be held in a fixture separated from the chamber to prevent conducted heat flow from the module. One module will have a 45-degree mirror, with a beam splitter coating and provisions on the side to attach the video camera.

The unit is nearly an exact copy of the illumination module built for the Apollo-Soyuz Salt Breakup experiment and as such is not a commercial model.

5.7.6 Anemometer

The anemometer is a laser doppler velocimeter. It uses the doppler shift of laser light scattered from particles in the fluid of the earth simulation sphere to measure the particle velocity. The fluid velocity is then inferred from the particle velocity. The optical system utilizes two dual-beam systems to measure velocity components in two directions. Due to the relationship of the rotation of the sphere and the fixed velocimeter, two velocities are seen. One velocity is the relatively fast component due to the sphere's rotation. The other velocity component is due to the relatively slow velocity of the particles in the field.

The principle of operation utilizes a hetrodyning technique. A laser beam is beam split. The two narrow beams of light wavelength λ are focused so they cross at a desired location. A fringe pattern is formed at this spot. As a particle passes through the set of straight parallel fringes, the intensity of

the scattered light varies sinusoidally. The scattered light is collected and focused on a detector. The output voltage frequency is proportional to the particle velocity. Since interference fringes are formed only at the beam crossing point, this defines the maximum measuring volume of the system.

The anemometer can be used to measure particle velocities in Experiments Classes 1 through 21. Its primary use is in Experiment Class 21. It will be fixed to the experiment table, looking through the transparent cylinder into the fluid particles in the revolving sphere.

A key feature of a laser is that its output radiation emerges highly collimated in the form of a diffraction-limited gaussian beam. This allows the radiation to be focused to high-power densities.

The optical power requirements would be from 5 mW to 1 watt.

The wavelength will be selected to optimize the functional requirements of the experiment. This laser assembly would also be used in the optical characterizers (scatterometer, liquid water content meter, and the drop size distribution meter) and for motion control or particle orientation.

5.7.7 Stereo Microscope

The stereo afocal microscope is the chamber observation instrument used by the astronaut to obtain enlarged views of the interior of the chambers. It is linked to the chamber by means of the coupling optics attached to the observational viewport. The recording camera, whether still or cine, sees the same field as the microscope through a beam splitter. There are two methods of obtaining a stereoscopic base and resultant convergent stereo angle.

If a stereo mirror set is attached to the viewport ahead of the coupling optics, the astronaut can obtain the normal stereo angle of 15 degrees. The camera will record both fields on one frame in a split field recording. Alternately, an additional lens can be incorporated to enlarge and record one field in the

double frame. Tilt and pan control will be restricted to about 5-degree total. The second method provides a smaller stereo convergent angle of about 5 degrees, but permits tilt and pan control to 15 degrees. The viewport is only slightly enlarged laterally since the two visual fields overlap considerably as they pass through the coupling optics. The camera will always record a monoscopic full double 35-mm frame.

In both methods, the stereo microscope sees parallel light coming from the object instead of the diverging light seen by the normal use of a microscope objective lens. Parallel light in and parallel light out of the microscope provides an afocal (nonimage forming) system. The afocal stereo microscope is not intended for high magnification viewing. It will provide magnifications up to 5X for observational purposes and act as a viewfinder for the camera as well.

5.7.8 Infrared Microscope

This instrument is a high spatial and temperature resolution instrument. It measures and records in real time the temperature of small water and ice particles and can be used to scan and map temperatures on a growing ice crystal. The instrument must measure temperatures between -40°C and ambient. At the lower end of the temperature range (230°K), the peak wavelength passive emission is at 12.5 μm. Thus the detector and its surroundings must be cooled to temperatures considerably below 230°K to prevent it from "seeing" its own internal radiation and to improve its detectivity and resulting temperature resolution and response. Depending on the temperature of the object and th distance involved (photons versus steradian capture), it may not be necessary to cool to cryogenic temperatures (77°K) to obtain the specified resolution. But cooling to levels of at least 200°K will be necessary. The window in the chamber used by the IR microscope will have to be made of a material transmitting wavelengths up to about 14 μm.

5.7.9 Support Equipment/Expendables

5.7.9.1 Coupling Optics

The depth of the experiment chambers necessitates a longer working distance than commercially available microscopes provide. In addition, when magnification is increased during use, the working distance shortens. The situation is also complicated by the three different depths resulting from three different sizes of chamber. To couple an observation microscope and a recording camera whether still, cine or video, to any chamber, a coupling tube incorporating coupling optics is provided. This permits reducing the amount of mechanical tubes and couplings, camera lenses and microscopes, which each chamber would have required, to one microscope and one camera zoom lens. It also permits the astronaut to vary the focal field of interest to follow differing depths and field angles of action. This capability is provided by the zoom coupling optics and the continuously variable tilt and pan adjustment.

5.7.9.2 Exposure Meter

To ensure that proper exposures will be made, an exposure meter will be provided. The proper exposure times will be developed in ground use of the CPL optical subsystem. Meter readings will be recorded so that the astronaut can check his illumination levels prior to turning on the film cameras. This is a reliability measure to prevent degrading the experiment data recording by improper exposures. The sensitometric properties of the film stock carried on each film will also be calibrated and related to the exposure meter. The exposure meter in turn will be calibrated for correct readings prior to flight.

This is a hand-held instrument. The sensing head is attached to the meter with a connecting cord. A small 9-volt battery will actuate the instrument.

7.9.3 Spools

For each sortie there will be differing film type and quantity requirements. The correct footage (plus contingency) on the correct size spools for the cameras to be used will be established before the flight. The film can be

ordered spooled to the correct length and tension from the supplier. Bulk film loaders are available for the small cassettes (36 exposures) for the still camera. For the astronaut's convenience, each spool will be properly loaded prior to flight so that on-orbit respooling will be unnecessary.

5.7.9.4 Film (35 mm)

Only black and white film will be utilized in the 35-mm perforated size. The 3414 emulsion will be used for the highest resolution requirements and Linagraph Shellburst for general recording. The supply will be rolled in both reels and large capacity cassettes (15 to 25 ft). The amount of film required for each experiment class was estimated and is used to establish expendable requirements. This unprocessed film must be stored at temperatures to prevent sensitometric changes.

5.7.10 Displays/Controls

    A.   Tip and tilt ±15 degrees of coupling optics and attached microscope and camera.

    B.   Camera frames per second speed controls will be required on the CPL control panel.

    C.   A two-position control to change zoom focus of the coupling optics and another to control zoom magnification for the cameras (both video and film) are on the CPL control panel.

    D.   A shutter actuation control is required which has a manual control mode and an automatic mode. In the automatic mode, the shutter is actuated by the camera control unit for strobed shots and/or time-lapse shots.

    E.   Frame advance should be automatic with each shot but with a "disable." When a particle can be strobed and recorded two, three, or more times on one frame, velocity determination is facilitated. Thus, actuation of the "disable" will allow controlled multiple exposures on one frame.

    F.   Displays — a digital frame counter will enable the astronaut to tell what footage he has consumed and how close he is to the end of the reel. The laser anemometer has a digital velocity meter. The

flashlamp circuit will have a ready light. Power to the following
should be indicated by a light:

      Coupling optics zoom

      Cine camera zoom

      Still camera zoom

      Video camera zoom

      Illumination module

The position of the zoom and the lens aperture setting will be displayed on
the lens barrel. The shutter speed setting will be displayed on the shutter
housing.

Section 6
LABORATORY SUPPORTIVE ANALYSES

The transfer of experimental research from a terrestrial laboratory to an orbital low-gravity environment necessitates the evaluation of the relationship of certain phenomenological factors. Additionally, specific engineering analyses are necessary to provide data for the selection of laboratory subsystems and assemblies. The analyses and trade studies presented herein are used to support the laboratory definition.

The relative importance of specific phenomenological factors is significantly altered by the absence of gravity. Many factors such as phoretic forces are of such a magnitude that they can be neglected within a terrestrial laboratory in comparison with other gravity-induced factors such as fall convection. On the other hand, the terrestrially important gravity-induced parameters change magnitude as a function of absolute acceleration. Successful laboratory design and experiment execution requires the evolution of the absolute and relative magnitudes of these factors.

The conduct of cloud microphysical experimentation in an orbital spacecraft also necessitates engineering evolutions of equipment design aspects trivial in a terrestrial laboratory. For orbital experimentation, unlike a terrestrial laboratory, relatively unlimited resources of sample gases, power, and manpower do not exist. Laboratory design evaluations to reduce expendables, to enhance experiment thermal control features, and to automate experiment operations become significant factors in concept definition. Additionally, manned aerospace operations necessitate consideration of safety, contamination, and commonality.

6.1 SUMMARY OF RESULTS
The significant results of these analyses are summarized in the following paragraphs with details of the individual analyses presented in the subsequent sections.

6. 1. 1 Aerosol Storage

When an aerosol is stored in a typical Faraday-cage-type Mylar bag container with linear dimensions of approximately 50 cm, the cloud nucleus concentration is typically terrestrially observed to decrease at a rate of about 5 percent per hour. If air motions occurring in the container are ignored, this cannot be explained by the combined action of diffusion, coagulation, and sedimentation.

A rough theory indicates that in ordinary laboratory conditions (with a temperature contrast of 0. 1°C to 0. 01°C across the container), convection currents flow at velocities of the order of 1 cm/sec; when the resulting flushing of the air close to the walls is modeled, convectively enhanced diffusion appears as by far the most important depletion mechanism; the theory predicts losses of 2 to 3 percent per hour. Since in a typical aerosol, coagulation and sedimentation together appear to cause a loss of less than 1 percent per hour, it is reasonable to attribute the rest of the observed loss (about 4 percent) to diffusion in the presence of convection currents.

According to the theory, the diffusional loss varies directly as the fourth root of both the temperature contrast across the container, and of the acceleration due to gravity, and inversely as the fourth root of the linear dimensions of the container. In an orbiting vehicle where gravity is reduced by a factor of 10^5 below its terrestrial value, the expected loss rate due to convectively enhanced diffusion with the usual temperature contrasts present would be about $(4 \times 10^{-5})^{1/4} = 0.2$ percent; that due to sedimentation would be negligible. Taking the loss due to coagulation as 0. 3 percent, the total loss rate would be about 0. 5 percent per hour. Some further reduction in the loss rate could be achieved by making the container more isothermal, but little could be gained by any practicable increase in size. Alternatively, for many purposes, it may be appropriate to reduce the coagulation loss by diluting the sample with particle-free air; in that case, the total could be essentially that due to convectively enhance diffusion, or about 0. 2 percent per hour. Thus a sample stored for half a day would be depleted by less than 2 percent, which for many purposes may be quite tolerable.

In the case of earth samples, it would be desirable to introduce a local sample (e. g. , a maritime aerosol at Cape Kennedy) into an already-stored container at a late stage during the preparations for launch. The effect of high gravity during injection into orbit on a stored aerosol is likely to be minor. Thus in the case of sedimentation, 3 g lasting for 200 seconds would remove as many particles as 1 g would in 600 seconds, that is about 0. 1 percent, while the loss caused by diffusion would be about $3^{1/4}$ times that which would occur on Earth in the same time period, i. e. about 0.3 percent per hour.

6. 1. 2 Chamber Operation

Sedimentation of the droplets which grow in the supersaturated environment of a cloud chamber is, of course, a very serious limitation in a terrestrial laboratory. For diffusion chambers with horizontal plates, it limits the usable range of supersaturations to above 0. 2 percent both in static and continuous chambers. When the plates are vertical, a convective cell is superimposed in the general flow and this considerably complicates the operation of the chamber. A chamber in zero-g would be largely free of these complexities and would be limited only by the transport of particles as a result of phoretic effects.

In an expansion chamber, the reduction in zero-g conditions of the convection currents due to differences between the wall temperature and that of the bulk gas is of the greatest importance. Following the analysis given in Subsection 6. 2. 6, the velocity of such currents will be of the order of $\left[(0. 1gkL/v)(\delta T/T)\right]^{1/2}$ where L is the characteristic dimension of the chamber. Thus, if δT can be kept as small as 0. 1°C, and g is reduced below its terrestrial value by a factor of 10^5, with L is taken to be 50 cm, a characteristic velocity will be of order 10^{-2} cm sec^{-1}, and the movement of the air as a result of convection will not produce significant transport of either heat or water vapor from the neighborhood of the walls to the central part of the chamber in periods less than several hundreds of seconds. Provided the pressure within the chamber is monitored during the expansion (or held constant) so that the interpretation of the experiment is not affected by volumetric changes due to the thermal influence of the walls on the immediately neighboring air, the only cause of departures from adiabatic conditions would be thermal conduction and vapor diffusion. In a chamber

of radius a = 25 cm, at time t = 100 sec, the departure from adiabatic of the central temperature ΔT is only a small fraction of the wall temperature, δT. Controlled wall temperatures can further reduce the thermal and vapor diffusion effects to negligible levels.

It is evident that experiments lasting a few hundred seconds would be possible, the acceptable duration being limited primarily by convective currents, the velocities of which would be proportional to $(g\delta T)^{1/2}$.

6.1.3 Gravity Levels
Acceleration levels for crew activities are 10^{-4} g and less, whereas the orbital environments are 10^{-6} g and less. The vernier thrusters if used would also by in the 10^{-4} g level. Orbital altitude should be greater than 150 nautical miles.

6.1.4 Aerosol Transport
Laminar tube flow results in aerosol losses which are a function of quantity flow rate $\dot{Q}$, and tube length, x. Losses can be decreased by increasing $\dot{Q}$ and/or decreasing x.

6.1.5 Radiation Pressure and Heating
Proper selection of the normal illumination levels required for visual and photographic purposes will not result in any adverse effects of heating or motion due to these optical sources. On the other hand, particle motion control and remote heating can be accomplished by proper selection of wavelength and power densities. The motion control will require a laser source to permit appropriate beam concentration and manipulation.

6.1.6 Air Ionization
The ionization level within a 200-mile earth orbit will have an appreciable effect only on those experiments involving highly charged droplets. The primary consequence would be a faster charge decay and this could be minimized by appropriate selection of orbit inclination, orbit position, and solar activity level. Decay time constants τ_o in orbit would be between $\tau_e > \tau_o > \tau_e/5$ where τ_e is the time constant observed in a terrestrial laboratory.

6.6.7 Contamination

The Cloud Physics Laboratory equipment will not affect the Spacelab or other payloads due to contaminants/contaminating environment. This assessment is based on evaluation of thermal control system leakage, acoustic fields, electromagnetic fields, and vibration characteristics of laboratory equipment. It was further assessed that the internal cleanliness of the CPL can be maintained to a 100 class product cleanliness level (current aerospace precision cleaning standard). Further study is however required to ascertain and quantify the exact requirements of individual experiment classes and the development of procedures and techniques associated with verification of such cleanliness levels.

6.1.8 Air and Water Quantity

The quantity of test sample gas and gas for cleaning and cleansing purges of the CPL has been established by Experiment Class. The maximum volumetric requirement has been established as 45.9 m^3 of standard atmospheric conditions. This requirement is to be satisfied by use of four Spacelab bottles.

The quantity of water required by diffusion cloud chamber wetted surfaces, the droplet generators, and the humidifier has been established as a maximum of 1.58 liters. A single 2.0-liter positive explosion water tank is provided to satisfy this requirement.

6.1.9 Cloud Chamber Thermal Design

The thermal and thermal control requirements of the cloud chambers can be satisfied by the use of heat pipe type control surfaces and thermoelectric modules interfacing with a 150 watt, 7° C Spacelab sink.

The significant results of the optical and imaging devices analyses are:

A. Visual Access — Due to the wall geometry of the chambers and the high resolution needed for the particle recording, flat optical quality wall viewports will be built into all chambers.

B. Focal Range — The interacting experiment particles occupy volumes at varying distances from the walls. A zoom-type coupling lens next to the viewport permits focusing to be controlled by the astronaut through one lens without affecting the focal setting of the microscope or the camera. Either the microscope or camera lens focal length may be changed to change magnification without affecting the focus on the particles.

C. Lighting — The illumination system will be filtered to eliminate the infrared content. Dichroic coatings on the spherical reflector and beam splitter will control the halogen-tungsten spectral content. Particles will be lighted from two sides and appear on a black background to enhance contrast and maximize resolution.

D. Viewports — These double-walled windows are made from flat optical-grade glass. Besides maximizing small particle resolution, the evenness of illumination is held, field distortion is minimized, and thermal leakage is minimized.

E. Distortion Calibration — The recording optics will be calibrated for radial and tangential distortion to minimize the plotting error in measuring particle velocity.

F. Data Management Requirements — Photographic and video frames will incorporate a digital time word. This will permit correlation to the timeline of other experimental data recordings.

G. Optical Subsystems Interactions — A trade study was made comparing zoom lens capability versus a set of interchangeable fixed-focus lenses. The conclusion was that a zoom lens was superior operationally but slightly inferior resolution wise.

H. Visual Resolution — Under optimum viewing conditions, the normal unaided visual acuity of high-contrast objects is about 1 minute of arc. To allow continued observation of nonoptimum illuminated, low-contrast particles, the magnification to be provided necessitates a set of optics covering the range from 2 X to 200 X.

6.2 EVALUATION DETAILS FOR THE PHENOMENOLOGICAL FACTORS

During the transfer, storage, and use of an aerosol there is a continuous decrease in the number density or concentration due to both coagulation of

the particles and adhesion of particles to the walls of the transfer tubes and storage containers. The choice of sizes used for aerosol transfer lines and storage containers and the length of times for which an aerosol can be stored in a given container must be based at least partially on a consideration of these losses. The physical sizes of the diffusion chambers are dictated to a large extent by such factors as vapor equilibrium time and vapor flux requirements. The actual useful time for a set of physical conditions then depends on both gravity effects (settling) and gravity independent effects (phoretic forces due to vapor and thermal gradients). All of these items must be considered to determine the operating conditions for the low-gravity environment.

6.2.1 Diffusion (Brownian)

If the air in the container is completely still, the diffusive loss of particles is negligible. For a spherical container of radius 1 cm, initially filled with an aerosol of concentration of N cm^{-3} and diffusivity D cm^2 sec^{-1}, the concentration at the center is given by Carslaw and Jaeger (Reference 1) as a function of time by:

$$\frac{N - N_c(t)}{N} = \frac{a}{(\pi Dt)^{1/2}} \sum_{n=o}^{\infty} \exp\left[-\frac{(2n+1)^2 a^2}{4Dt} \right]$$

The infinite series is dominated by the expansion of $z/1-z^8$ where $z = \exp(-a^2/4Dt)$, so that the proportional decrease in the central concentration at time t is $\left[(N-N_c(t))/N \right]$ is less than $\left[(a/(\pi Dt)^{1/2})/(z/(1-z^8)) \right]$.

For $a = 25$ cm, $D = 3.6 \times 10^{-5}$ cm^2 sec^{-1}, $t = 3.6 \times 10^3$ sec, $z \sim \exp(-1205)$, so that

$$\frac{N - N_c(t)}{N} \sim \frac{a z}{(\pi Dt)^{1/2}}$$

$$\sim 40 \exp(-1205)$$

$$\sim 10^{-516}$$

Clearly, the effect of diffusion at the center of a container with a "diameter" of 50 cm in which the air remains quite still is totally negligible. It is unrealistic to assume that the air in the container will remain stationary for periods of the order of hours, and a rough theory indicates that diffusive losses would be much larger than predicted above, as a result of convective motions caused by minor temperature differences, which under ordinary laboratory conditions would probably be of the order of $0.1°C$, or perhaps as small as $0.01°C$.

6.2.2 Phoretic Forces

Thermo-, diffusio, and photo-phoretic forces impart velocities to particles in the experimental area. The forces tend to reduce the experimental observation time due to the induced motion of particles out of experimental area or to the storage chamber walls. An estimate of the magnitude of these forces will be given.

Thermophoresis is the influence of temperature gradients in a gas on aerosol particles.

Diffusiophoresis is the influence of concentration gradients in a gas on aerosol particles.

Photophoresis is the influence of temperature differences within the surfaces of the aerosol particle caused by irradiation with light.

General discussions concerning these forces can be found in books edited by Davies (Reference 2) and Fuchs (Reference 3).

6.2.2.1 Diffusiophoretic and Thermophoretic

The diffusiophoretic velocity (V_D cm/sec) of submicron aerosol particles in an air-water vapor mixture was determined experimentally (Reference 4) and theoretically (Reference 5) to be:

$$V_D = -1.9 \times 10^{-4} \frac{dp}{dX} = -3.2 \times 10^{-4} \frac{dT}{dX}$$

where

$$\frac{dp}{dX} = \text{water vapor pressure gradient } \frac{mb}{cm}$$

$$\frac{dT}{dX} = \text{temperature gradient (}^\circ C/cm)$$

The thermophoretic velocity $(V_T, cm/sec)$ of similar particles in air was experimentally found by Goldmith and May to be:

$$V_T = -2.6 \times 10^{-4} \frac{dT}{dy}$$

Theoretically the diffusiophoretic and thermophoretic velocities are additive:

$$V_P = -5.8 \times 10^{-4} \frac{dT}{dX}$$

The theory is substantiated by the good agreement between the experimental and theoretical data as indicated in Figure 6-1 where the circles are the experimental data points and the solid curves are the theoretical results.
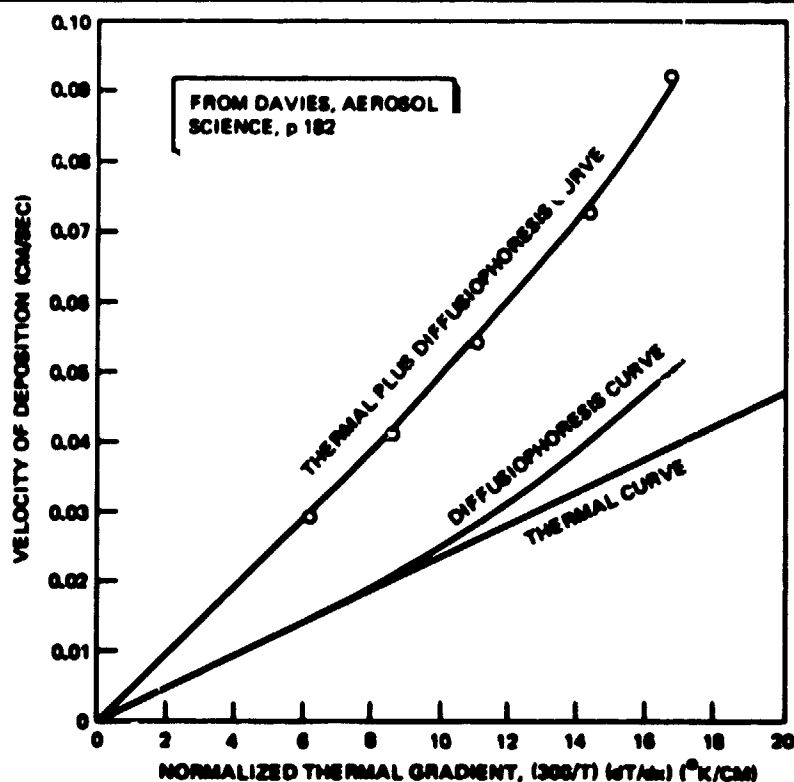
Figure 6-1. Velocity of Particles in Superimposed Thermal and Water-Vapor Pressure Gradients

Figure 6-2 shows a comparison of theory with experimental data taken in
a supersaturated atmosphere. The enhanced velocity shown in this figure
at higher temperature gradients is due to the gravity-induced sedimentations
caused by the diffusional growth of large particles activated by the large
supersaturations. The excellent agreement between theory and experiments
indicates that these equations can be used to estimate the corresponding
effects in a low-gravity environment.

The residence time of a particle in a thermal gradient of dT/dx (76 cm Hg,
23°C) is given by:

$$\text{Residence Time (R. T.)} = -\frac{(1.724 \times 10^3 \ L)}{dT/dx}$$

where L is the distance moved by the particle in a time t (sec).

The residence time for L = 2, 3, 4 mm is shown in Figure 6-3.
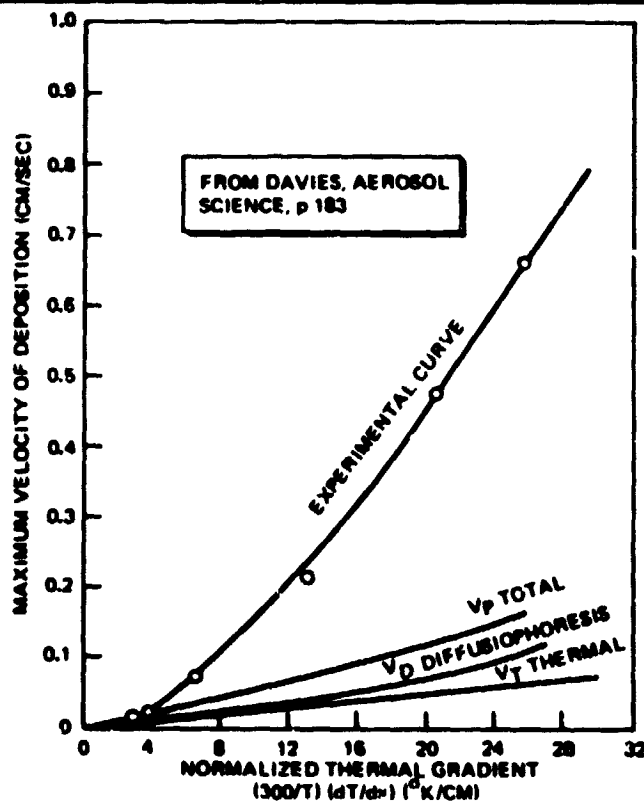
Figure 6-2. Enhanced Velocity of Deposition in a Supersaturated Atmosphere
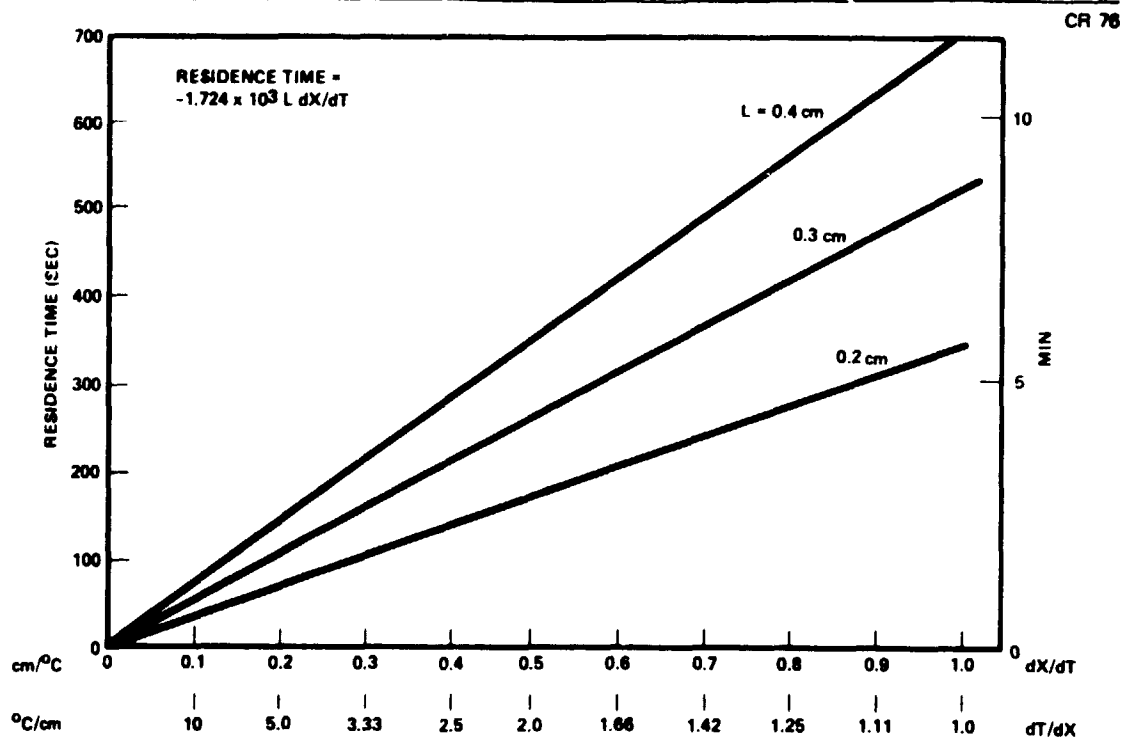
Figure 6-3. Thermo- and Diffusiophoretic Forces

Anticipated thermal (and associated diffusion) gradients for low-gravity applications are 2°C/cm to 0°C/cm with limited study requirements of up tc 5°C/cm. From Figure 6-3, 2-mm movement will require 150 sec to greater than 300 sec, an increase of two decades compared with equivalent horizontal terrestrial chamber which are gravity-induced sedimentation limited. These times are sufficient for the specified cloud microphysics experiments.

6.2.2.2 Photophoresis

Photophoresis is produced by the so-called radiometric forces, which because of the gaseous medium act upon nonuniformly heated particles present in the medium. The mechanism of radiometric forces depends essentially upon the magnitude of the proportion of the particle radius to the mean length of the gaseous molecular free path. When the particle radius, r, is less than the mean length of gaseous molecular free path, l, the radiometric force is developed due to the fact that gaseous molecules are

repulsed from the hotter side of the particle with a velocity greater than from the cooler side. That is why particles transmit impulses directed toward a lower temperature. The magnitude of this force, as molecular-kinetic computation indicates, is equal to (Reference 6):

$$F_M = \frac{\pi \alpha P r^3 \nabla i}{3T}$$

where

α = coefficient of accommodation of gaseous molecules on a particle surface

∇i = temperature gradient inside a particle

P = pressure

T = temperature

In terms of basic material parameters this equation becomes:

$$F_M = \frac{-3\pi^2 r R_g I}{2 \overline{P} M (X_a + X_i)}$$

where

η = viscosity of the medium

R_g = gas constant

M = molecular weight

X_a = heat conductivity of the gas

X_i = heat conductivity of the particle

I = power per cm^2 absorbed by particle

The photophoretic forces (F_M) were calculated for two cases: (1) xenon flash tube producing an average energy density of 134 watts/cm^2 in a 1-millisecond pulse; (2) CW tungsten halogen lamp producing an average energy density of 5 watts/cm^2.

Using:

$$\eta = 1.5 \times 10^{-4} \text{ dynes-sec/cm}^2$$

$$R_g = 8.32 \times 10^{7} \text{ ergs/}^\circ\text{C mole}$$

$$\alpha = 0.001$$

$$P = 760 \text{ mm Hg}$$

$$M \equiv 28 \text{ grams/mole}$$

$$X_a \equiv 6 \times 10^{-5} \text{ cal/cm-sec-deg}$$

$$X_i = 1.43 \times 10^{-3} \text{ cal/cm-sec-deg}$$

Stokes law for the force of resistance of a medium to translation (F_s) is given by:

$$F_S = 6\pi\eta r V.$$

Equating F_s to the forces due to the photophoretic forces, the terminal velocity (V) for the particles can be calculated.

$$V = \frac{F_m}{6\pi\eta r}$$

The force acting on a submicrometer particle, the resulting velocity and the time and distance to achieve this terminal velocity are given in Table 6-1. For comparison the terminal velocity of a 1-micrometer-diameter droplet acted on by 1 g is 0.003 cm/sec and at 10^{-5} g would be 3.0×10^{-8} cm/sec. Comparing these with Table 6-1 show that the photoporetic forces (radiometric) associated with the normal irradiation intensities for visual purposes remain inconsequential even in a 10^{-5} g environment.

6.2.3 Thermal (Brownian) Coagulation

In any aerosol experiment, consideration must be given to the coagulation and diffusional losses of the particulate matter. These phenomena are understood

Table 6-1

ASSESSMENT OF RADIOMETRIC FORCES

	Force, F_M (dynes)	Velocity, V (cm/sec)	Relaxation Time, t (sec)	Relaxation Distance, X (cm)
Case 1	3.48×10^{-24}	2.46×10^{-17}	3.53×10^{-6}	43×10^{-24}
Case 2	1.3×10^{-25}	9.2×10^{-18}	3.54×10^{-5}	16×10^{-23}

well enough so that their influences can be predicted mathematically. Coagulation follows the following relationship:

$$\frac{dn}{dt} = \frac{Kn^2}{2}$$

where K, the coagulation kernel, is determined primarily by the particle size; and the factor 1/2 has been added so that each aggregate should be counted only once. This equation was first deduced by Smoluchowski (References 7 and 8) in 1916, and has been verified since then by several independent investigations (References 9 and 10). This expression for the particle number density, n, as a function of time, t, is a good approximation in most cases. This is because of two counteracting effects (References 11 and 12): (1) "Wiegner Effect" (Reference 13) - coagulation rates of small particles increases in the presence of larger particles, and (2) the increase in mean particle size reduces the value of the coagulation kernel, K. Thus, these two effects tend to cancel one another out, and the aerosol system as an entity behaves as a monodisperse system.

In the analysis, no consideration was given to wall losses since this loss is a function of the geometry of the system.

In general, wall losses can be approximated by:

$$\beta = \frac{\text{Surface Area}}{\text{Volume}} \times \frac{D}{\delta}$$

where δ is the wall layer thickness and has an approximate magntiude (Reference 14) of $\delta = 5 \times 10^{-5}$ cm. As an example for a spherical chamber,

$$\beta = \frac{D \, 4\pi r^2}{\delta \, \frac{4}{3}\pi r^3} = \frac{3D}{R\delta}$$

and so for large R and small D (diffusion coefficient) the loss to the walls is minimized. The wall loss can be included in Smoluchowski's equation to give

$$\frac{dn}{dt} = -Kn^2 - \beta n.$$

From this equation, it can be seen that for concentrations of 10^5 or larger coagulation is the predominant mechanism. For concentrations of 10^3 or less the diffusional loss to the walls must be also considered.

Since any aerosol can be easily neutralized (Reference 15) to the Boltzmann's charge distribution, there is no need to calculate the effect of charge on the aerosol. The surrounding walls, however, should be conducting so that no appreciable surface charge can accumulate. In some plastic containers (Reference 16), high surface charges greatly increase the loss of particles to the walls.

Figures 6-4 and 6-5 are plots of the integrated form of the coagulation equation

$$\frac{n}{n_o} = \frac{1}{1 + n_o \frac{Kt}{2}}$$

for initial concentrations, n_o, of 10^3, 10^4 and 10^5 particles per cubic centimeter with (monodispersed) particle radii, a, of 0.1 and 0.005 microns. The values of the coagulation kernel have taken into account the gas correction
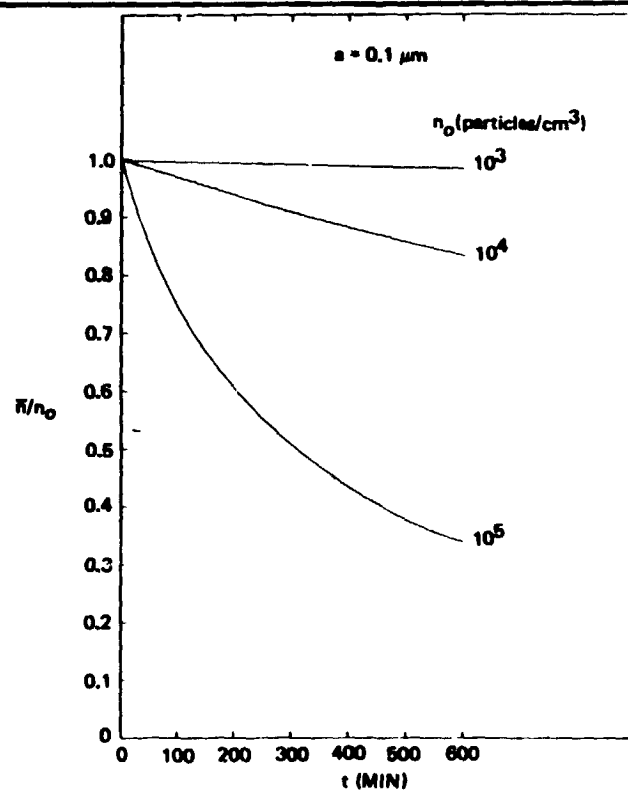
Figure 6-4. Coagulation Rates for Monodisperse Particle Radius a = 0.1 μm
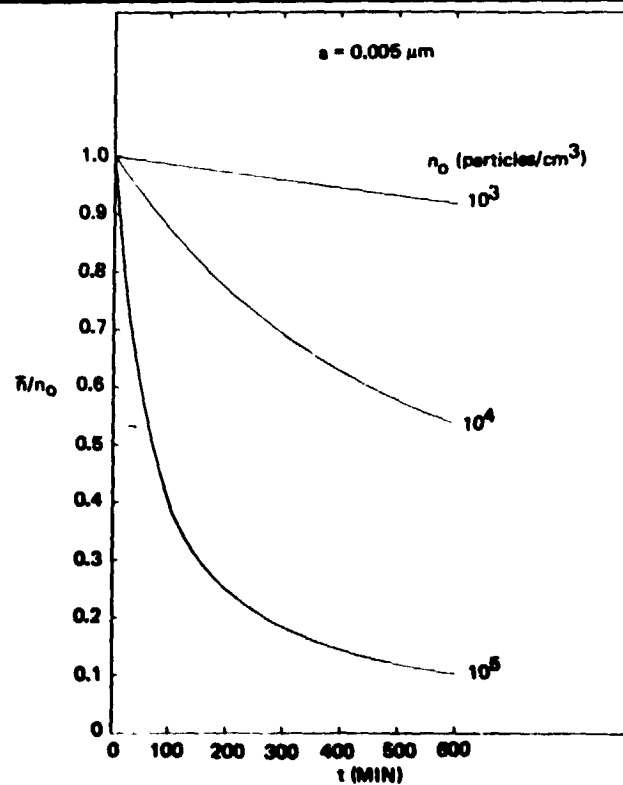
Figure 6-5. Coagulation Rates for Monodisperse Particle Radius a = 0.005 μm

term and have been compiled by G. Zebel (Reference 17). The correction term is obtained by equating the diffusional flux to the kinetic flux at a distance of one mean free path from the absorbing surface. The correction allows the diffusional equation, which is based on continuum theory, to be extended into the gas kinetic regime.

The zero-gravity CPL program has identified particle density ranging from 3×10^4 particles/cm^3 and lower with diameters from 0.01 μm to a few micrometers. Figures 6-4 and 6-5 indicate that storage times of 3 to 5 hours will result in less than 50 percent decay due to coagulation. Many of the experiments require concentrations of less than 10^3 particles/cm^3 and particle diameters greater than 0.1 μm. For these experiments the coagulation rate will be well below a few percent per hour.

6.2.4 Sedimentation

Particle motion due to residual acceleration levels effect experiment procedures and observation requirements. The impact of these effects can be most conveniently evaluated by considering several particle size ranges. First the loss of nuclei (submicrometer particles) to the container walls due to acceleration induced sedimentation is considered. Then the motion of droplets moving at terminal velocities in a reduced gravity or acceleration field is considered. Next an evaluation is presented for the general motion of a free-floating drop over a complete orbit due to such things as gravity gradient, earth oblateness, and residual atmospheric drag. These latter calculations were done in a general form assuming that the drop was moving in a vacuum environment within Shuttle/Spacelab. The results indicate that a minimal orbital altitude of 150 nautical miles is desired for Cloud Physics Laboratory experiment operations.

The final evaluation provides information showing that preferential orientations for droplet injection relative to visual observations exist and should be considered for special experiments requiring optimum motion control. This analysis also established the stopping distance for a 100-μm-diameter droplet with two initial velocities and for various chamber orientations.

6.2.4.1 Nuclei

If the air in the container was completely at rest, the number flux of particles in the range r_1 up to r_2 through any horizontal plane would be simply

$$\int_{r_1}^{r_2} V_s \, dN,$$

where N is the cumulative concentration. For sufficiently large particles, this formula is valid not only in the bulk gas, but also at a horizontal wall surface, but in the case of sufficiently small particles, it is not valid to assume that their concentration very close to the wall is the same as in the bulk gas, since that concentration already is much reduced by Brownian diffusion. However, sedimentation is an effective process throughout most of the range of sizes corresponding to cloud nuclei, and in the present discussion it will be assumed that the function N is everywhere the same.

In order to evaluate the integral $\int V_s dN$, it will be assumed that the size distribution follows Junge's law, $dN/d\ell nr = \alpha r^{-3}$ from $r = r_2$ (the maximum size) down to $r = r_1 = 5 \times 10^{-6}$ cm, and that from $r = r_1$ down to the lower limit of cloud nucleus sizes r_m ($\sim 2 \times 10^{-6}$ cm), $dN/d\ell nr$ is a constant. The total count of particles from the maximum radius down to r_m is then:

$$dN = \int_{r_1}^{r_2} dN + \int_{r_m}^{r_1} dN$$

$$= \int_{r_1}^{r_2} \alpha r^{-3} d\ell nr + \left(\frac{dN}{d\ell nr}\right)_{r=r_1} \ell n \frac{r_1}{r_m}$$

$$= \frac{\alpha}{3}\left(r_1^{-3} - r_2^{-3}\right) + \alpha r_1^{-3} \ell n \frac{r_1}{r_m}$$

$$\approx \alpha r_1^{-3} \left(\frac{1}{3} + \ell n \frac{r_1}{r_m}\right)$$

since $r_1^{-3} \gg r_2^{-3}$

Taking $r_1 = 5 \times 10^{-6}$ cm, $r_m = 2 \times 10^{-6}$ cm, this implies that the total cloud nucleus concentration (n) is close to $1.25 \, \alpha \, r_1^{-3}$. Hence $\alpha = 0.8 \, n \, r_1^3$.

The sedimenting flux through unit area of a horizontal plane is

$$\int_{r_m}^{r_2} V_s dN = \int_{r_1}^{r_2} V_s dN + \int_{r_m}^{r_1} V_s dN.$$

The fall velocity, V_s is given by:

$$V_s = \frac{4}{3} \pi r^3 \rho_p g B$$

where ρ_p is the density of the particles and B their mobility. Thus,

$$\int_{r_1}^{r_2} V_s dN = \frac{4}{3} \pi \rho_p g \alpha \int_{r_1}^{r_2} r^{-1} B dr$$

The empirical formula due to Knudsen and Weber (Reference 18) and Millikan (Reference 19) is:

$$B = \left[1 + \frac{A\ell}{r} + \frac{Q\ell}{r} e^{-br/\ell} \right] /6\pi \ell r$$

where A ≈ 1, and ℓ is the mean free path of air molecules. The value of Q and b have been estimated from experiments with various aerosols, and depend somewhat on the constitution of the particles. Taking the results of Millikan for oil droplets in air, $Q \simeq 0.3$, $B \simeq 1.25$.

This gives the sedimenting number of flux as:

$$\int_{r_1}^{r_2} V_s dN = \frac{2}{9} \frac{\rho_p g^\alpha}{\eta} \int_{r_1}^{r_2} \left(r^{-2} + A\ell r^{-3} + Q\ell r^{-3} e^{-\frac{br}{\ell}} \right) dr$$

$$= \frac{2\rho_p g^\alpha}{9\eta} \left(-r^{-1} - \frac{A\ell r^{-2}}{2} + \frac{Q\ell}{2} \{ -r^{-2} e^{-pr} \right.$$

$$\left. + pr^{-1} e^{-pr} + p^2 Ei(-pr) \} \right) \Big|_{r_1}^{r_2}$$

where $p = b/\ell$.

Putting $r_1 = 5 \times 10^{-6}$, $r_2 = 5 \times 10^{-4}$, $p = 2 \times 10^5$, since $Ei(-1) \approx -0.2$, it results that all terms are small compared with the first two, and we may write, approximately:

$$\int_{r_1}^{r_2} V_s dN = \frac{2\rho_p g^\alpha}{9\eta} \left(r_1^{-1} + \frac{A\ell}{2} r_1^{-2} \right)$$

Also, since in the range r_m to r_1, it is assumed that

$$\frac{dN}{d\ell nr} = \alpha r_1^{-3},$$

$$\int_{r_m}^{r_1} V_s dN = \frac{2\rho_p g^\alpha r_1^{-3}}{9\eta} \int_{r_m}^{r_1} (r + A\ell + Q\ell e^{-pr}) dr$$

$$= \frac{2\rho_p g^\alpha r_1^{-3}}{9\eta} \left[\frac{1}{2} r^2 + A\ell r - \frac{Q\ell}{p} e^{-pr} \right]_{r_m}^{r_1}$$

Substituting $= 0.8\, n\, r_1^3$ and, later, putting $\rho_p = 1.5\ \text{g cm}^{-3}$,

$$\int_{r_m}^{r_2} V_s \, dN = \frac{1.6 \rho_p g n}{9\eta} \left[r_1^2 + \frac{A\ell r}{2} 1 + \frac{1}{2}\left(r_1^2 - r_m^2\right) \right.$$

$$\left. + A\ell (r_1 - r_m) - \frac{Q\ell}{p}\left(e^{-pr_1} - e^{-pr_m}\right) \right]$$

$$\approx 1.5 \times 10^6 n \left\{ \frac{3}{2} r_1^2 - \frac{1}{2} r_m^2 + A\ell\left(\frac{3}{2} r_1 - r_m\right) \right.$$

$$\left. - \frac{Q\ell}{p}\left(e^{-pr_1} - e^{-pr_m}\right) \right\}$$

$$\approx 10^{-4}\, n \qquad \text{(particles per unit area, per unit time)}$$

where n is the total cloud nuclei concentration.

Thus, in a container h cm deep and one-g environment, the proportional rate of loss of cloud nuclei due to sedimentation from still air is $10^{-4}/\text{h}$ per second, or about 0.7 percent per hour for h = 50 cm. The above analysis indicates the resulting sedimentation losses are proportional to the ambient acceleration level. Thus sedimentation losses in a 10^{-3} g environment are negligible.

6.2.4.2 Cloud Droplets
The following analysis considers the motion of particles larger than nuclei but in the Reynolds number range for which the Stokes approximation applies (Re << 1).

For lower gravity the formulas for the terminal velocities of drops are:

Stokes Law gives (at terminal velocity)

$$F = 6\pi\eta\, rv = 4\pi\, (\rho - \rho')\, r^3 g/3$$

$$\therefore v = 2(\rho - \rho')g r^2/\eta$$

$$Re = 4(\rho - \rho')g r^3/9\, \nu^2 \rho'$$

where

$\nu = \eta/\rho' = $ kinematic viscosity of air

$\eta = $ dynamic viscosity of air

$\rho' = $ density of air

$\rho = $ density of water

$r = $ drop radius

$g = $ acceleration due to gravity

$g_e = $ acceleration due to gravity at earth's surface

$Re = $ Reynolds number

From the above relationship for velocity, it can easily be shown that

$$\frac{v}{v_e} = \frac{g}{g_e}$$

where v and g are the velocity and acceleration in some general (e. g. , orbital) environment and v_e, g_e are the respective earth values.

The above relationship is for drops at terminal velocity under the influence of an ambient acceleration level. Thus, the terminal velocity of the particle in air will scale directly with the acceleration level.

6. 2. 4. 3 Raindrops

The following analysis considers the effect of orbital laboratory motion on larger particles. When a free-floating droplet is placed inside an orbiting spacecraft, it will exhibit relative motion with respect to the center of gravity of the vehicle due to atmospheric drag, earth oblateness, and orbit altitude. This analysis was performed to establish the motion of such a droplet moving in a vacuum within the spacecraft.

The coordinate system employed is a rotating axis system with the origin placed at the center of gravity of the orbiting satellite. The x-axis is always

kept aligned with the velocity vector - positive in the direction of motion of the satellite. The z-axis is assumed to be in the plane of the orbit — positive toward the center of gravitational attraction (aligned with the radius vector of the orbit). The y-axis completes the conventional right-handed coordinate system being normal to the orbit plane — positive to the right.

Analytical Development (Closed Form)

To obtain an insight to the problem at hand, namely the motion of a "raindrop" inside a satellite with respect to the center of gravity of that satellite, simple closed-form equations were used. Assumptions that were made that would affect the results were:

- Spherical earth, no atmosphere
- Circular orbit
- Drop moving in a vacuum
- Initial perturbations to have a small effect on the orbit of the raindrop

Of particular importance is the last assumption when perturbations involve velocity. The incremental velocities should be small enough so that, for example, $\dot{x}_o$ would not markedly affect the vertical displacement of the "raindrop." Thus, $\dot{X}_o = 30$ cm/sec (1 ft/sec) would be way too large as the vertical displacement that would result due to the velocity alone would be approximately 1 km (3,300 ft).

With these assumptions in mide, the equations for the relative positionof the raindrop are:

$$X = X_o + \dot{X}_o t - 6Z_o (\omega_o t - \sin \omega_o t) - \frac{2\dot{Z}_o}{\omega_o} (1 - \cos \omega_o t)$$

$$Z = Z_o (4 - 3 \cos \omega_o t) + \frac{\dot{Z}_o}{\omega_o} \sin \omega_o t$$

and no motion out of the plane of the orbit.

In an example where

$$\dot{X}_o = \dot{X}_o = \dot{Z}_o = 0$$

$Z_o = -30$ cm (-1 ft)   (30 cm (1 foot) above the center of gravity of the satellite)

$$\omega_o = \frac{V_o}{r_o}$$ satellite at approximately 100-nmi altitude

$X = -12$ meters   (in one orbit)
(-38 feet)

$Z = -2.1$ meters   (in one-half orbit returning to the original
(-7 feet) $Z = -30$cm (1 ft) position at the end of the orbit)

Note that whereas the vertical displacement cycles from -30 to -210 cm
(-1 to -7 feet) displacement (backward) along the orbit increases by 12
meters (38 ft) subsequent orbit.

Increasing the initial displacement also increases the subsequent displace-
ment by the same factor. Thus doubling the initial displacement would also
double the subsequent maximum excursion of the particle.

Exact Analysis

The exact analysis was performed with micrometric precision afforded by the
GVPAT computer program in its "odd-ball" configuration. In this program
the equations of motion are integrated, allowing exact comparison of the
positions of the center of gravity of the satellite with that of the "raindrop."
The detail of the analysis is only limited by the complexity of the model
(earth gravitational potential, atmosphere, guidance, etc.).

A stepping stone approach was taken in the analysis to allow the reader to
walk from the closed form results to the more complex modeling of the
problem.

Step 1

The example most closely resembling the closed-form solution is the
integrated case having no atmosphere and assuming a spherical earth.
This case gave extremely close agreement with the theoretical closed-
form results.

Step 2

The addition of standard atmosphere to the model drastically changes the results. Although the spacecraft, i.e., the Shuttle Orbiter, was always rotated so as to present the lowest drag profile, considerable changes were experienced in the orbit of the spacecraft itself, approximately 72 meters (240 feet) along the flight path and the noncyclic nature of the disturbance along the radius vector.

Step 3

The inclusion of earth oblateness effects essentially did not modify the disturbances as calculated in Steps 1 and 2. The only effect being the appearance of a lateral displacement due to the regression of the orbital plane. This lateral displacement being 0.34 meter (1.14 feet) and 2.34 meters (7.8 feet) for the nonatmospheric and atmospheric case, respectively.

Step 4

Increasing the orbit altitude essentially decreases the effect the atmosphere has on the spacecraft and the relative motion of the particle with respect to the center of gravity reverts back to the theoretical case.

The effect of orbit altitude on the displacement history of the raindrop is summarized in Figures 6-6, 6-7, and 6-8. From these figures it can be seen that most of the atmospheric effects on the orbiter have been eliminated by 280km (150 nmi). However it should be pointed out that the attitude of the orbiter with respect to the velocity vector as well as variations in the atmospheric density would play a very important role.

6.2.4.4 Orientation and Air Drag Effects

Don Klick of the NASA/MSFC analyzed the effects of experiment package orientation on drop dynamics as relevant for an Apollo-type cloud physics experiment. The results are included here to show qualitatively the various effects of chamber orientation. Included are both initial drop velocities and chamber air drag.

Gravity forces, atmospheric drag on the spacecraft, drag on the drop due to the cabin atmosphere, as well as initial drop velocities due to injection techniques were considered in the analysis.
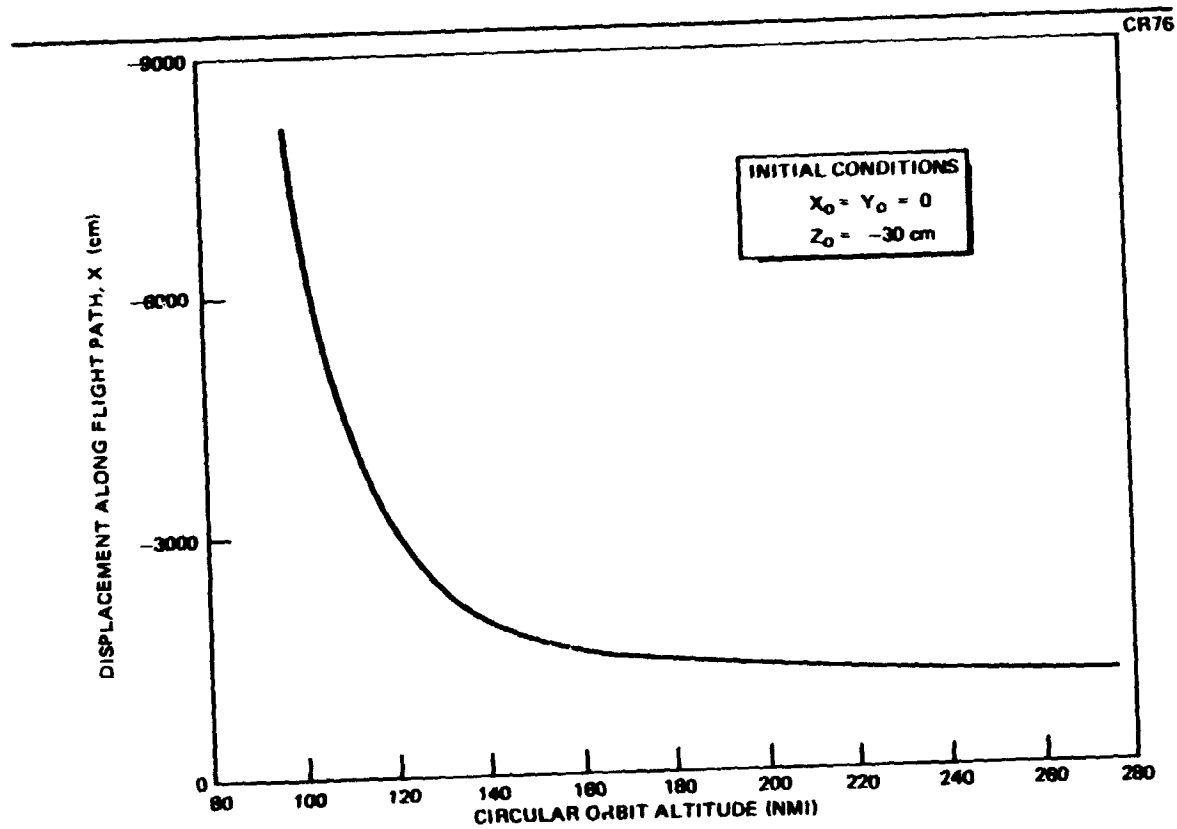
Figure 6-6. Orbit Altitude Effect on Raindrop – X Axis Displacement
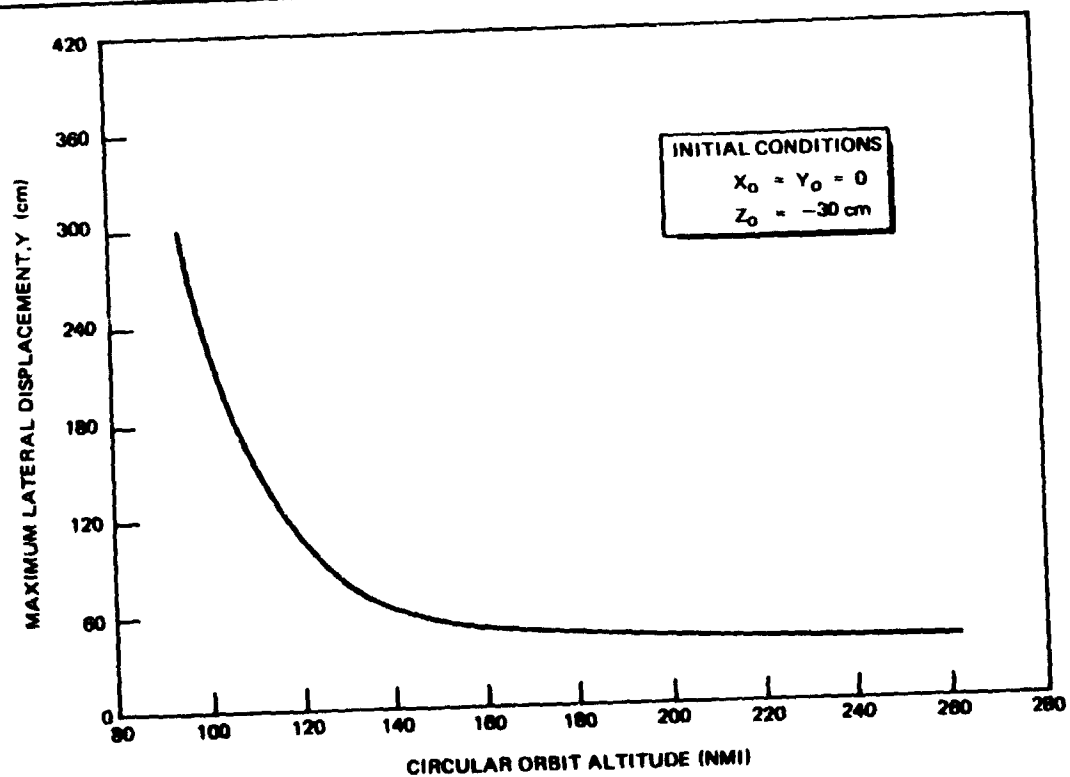
Figure 6-7. Orbit Altitude Effect on Raindrop – Y Axis Displacement
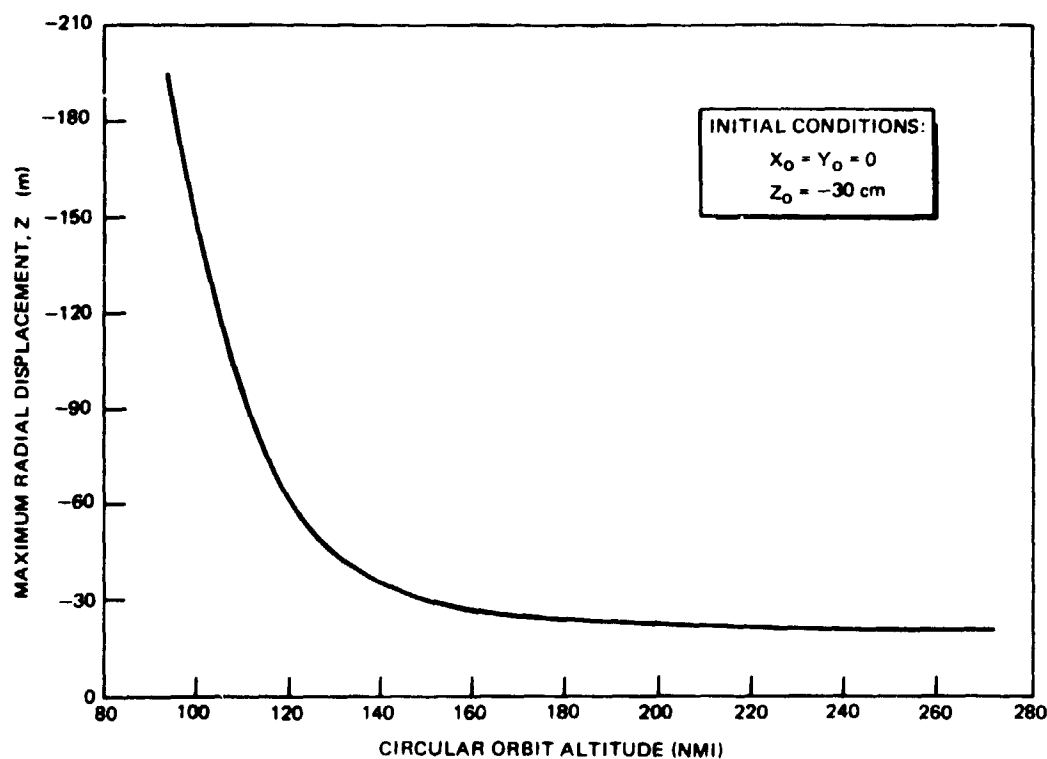
Figure 6-8. Orbit Altitude Effect on Raindrop — Z Axis Displacement

Displacements are presented for a droplet when the experiment package is placed in six different orientations. In each case, the package was considered to be at the same location in the spacecraft. In all of these orientations, the spacecraft velocity vector is directed along the positive x direction, and the spacecraft is in a z-local vertical mode with an orbit radius of 146 nmi. A z-local vertical mode positions the spacecraft such that the positive z axis is continually aligned with a radius vector from earth to the spacecraft, and the positive x axis is continually tangential to the circular path of the orbiting spacecraft. The positive y axis is chosen to make a right-handed coordinate system.

Figure 6-9 contains calculated displacements of a 100-μm saturated salt water particle injected into a medium of 70 to 30 percent nitrogen-oxygen mixture which has a viscosity of 0. 185 x 10^{-4} kg/m-sec. The particle displacement is calculated for initial velocities of 10 cm/sec and 25 cm/sec with positive and negative injection directions along various injection axes. The displacements as calculated and tabulated are total displacements which relfect the distance traveled by the particle from the injection point at the end of a representative experiment time (30 minutes).

DISPLACEMENT (M)

ORIENTATION	INJECTION DIRECTION	INITIAL VELOCITY (CM/SEC)	INJECTION AXIS	VIEW AXIS	AUXILIARY AXIS
I	+X	10	0.0047879	0.0000802	0.0000266
		25	0.0101365	0.0000807	0.0000266
	-X	10	0.0023435	0.0000796	0.0000266
		25	0.0076920	0.0000792	0.0000266
II	+X	10	0.0047879	0.0000266	0.0000802
		25	0.0101365	0.0000266	0.0000807
	-X	10	0.0023435	0.0000266	0.0000796
		25	0.0076920	0.0000266	0.0000792
III	+Y	10	0.0035388	0.0000799	0.0012222
		25	0.0088868	0.0000799	0.0012222
	-Y	10	0.0035919	0.0000799	0.0012222
		25	0.0089400	0.0000799	0.0012222

Figure 6-9. Particle Displacement in Various Package Orientations (Sheet 1 of 2)

ORIENTATION	INJECTION DIRECTION	INITIAL VELOCITY (CM/SEC)	DISPLACEMENT (M)		
			INJECTION AXIS	VIEW AXIS	AUXILIARY AXIS
IV	+Y	10	0.0063398	0.0012222	0.0000799
		25	0.0088868	0.0012222	0.0000799
	-Y	10	0.0035919	0.0012222	0.0000799
		25	0.0089400	0.0012222	0.0000799
V	+Z	10	0.0036465	0.0012219	0.0000266
		25	0.0089965	0.0012215	0.0000266
	-Z	10	0.0034867	0.0012225	0.0000266
		25	0.0088366	0.0012230	0.0000266
VI	+Z	10	0.0036465	0.0000266	0.0012219
		25	0.0089965	0.0000266	0.0012215
	-Z	10	0.0034867	0.0000266	0.0012225
		25	0.0036465	0.0000266	0.0012230

Figure 6-9. Particle Displacement in Various Package Orientations (Sheet 2 of 2)

As seen in Figure 6-9, two sets of coordinate systems for each of the six cases were used to help clarify the orientations. The spacecraft coordinate system (x, y, z) remained unchanged in every case, while the axes on the package coordinate system are rotated and interchanged so as to determine the effect of various orientations on the salt water particle displacement. The experiment package coordinate system consists of an injection axis along which the particle is directed, a view axis along which the photographic and optic apparatus is situated as well as a third or auxiliary axis. All three of these are important in determining the experiment package size. However, if depth of field considerations make it desirable to minimize motion along the view axis, it is possible to select an orientation which does this. If instead field of view is the more restrictive requirement, motion in the plane formed by the injection and auxiliary axes can also be minimized.

The results in Figure 6-9 indicate that the smallest total displacements occur in both case I and case II when the injection is made in the negative x direction. This indicates an orientation for minimizing package size. The smallest displacements along the view axis were observed for orientations II and VI, and these indicate optimum orientation for depth of field.

Most experiments will not require any special orientation beyond the consideration of being as near the center of gravity of the orbital platform as possible. This information can be utilized for those special cases where camera depth of field is critical and motion must be minimized in that direction.

6.2.5 Convection

The following order-of-magnitude theory for determination of the loss of particles from air due to convective circulation was developed by P. Squires during his program participation.

Consider a container with linear dimensions L; and suppose that the temperature of one wall is $\delta T^\circ C$ higher than the opposite one. An upward motion will occur near the warmer wall, a downward one near the colder using normal one-g terminology. The momentum of the moving air is generated by buoyancy forces in those regions where the temperature of the air has been significantly influenced by the neighboring wall, and suffers attrition as a result of viscous stresses. The temperature anomaly relative to the mean of a circulating parcel is reversed twice per revolution by heat conduction to and from the wall; no other mechanism significantly influences

the temperature of the parcel. On the other hand, the momentum anomaly of the parcel is reversed twice per revolution very largely as a result of the action of pressure forces which change the descending current to a horizontal one, and then into an ascending current. The scalar gradient of velocity from the region of maximum velocity to the wall is essentially unchanged during this process, while the gradient of temperature is reversed. Thus, although the diffusivity of momentum in air (the kinematic viscosity) is less than the diffusivity of heat, the nonsteady aspect of the diffusion processes is of little significance for momentum, but is of the essence of the problem in the case of heat.

The vertical velocity will have an S-shaped distribution, vanishing in the middle and at the walls. Let v be the maximum velocity, which will occur somewhere between a wall and the center. Let the distance from the wall to this point be y. Then, air near the velocity maximum will traverse the length of the wall in time $T = L/v$. It is plausible that at the location where v occurs, the air temperature will be largely controlled by the wall. Otherwise, the convection current would not reach its maximum velocity there.

When a semi-infinite slab of material with a thermal diffusivity of k and an initial uniform temperature T_1 is placed in good thermal contact with a surface which is held at a fixed temperature T_0, heat diffuses through the material in a manner defined by

$$(T - T_0) = (T_1 - T_0) \, \text{erf} \, (y/2\sqrt{\kappa t})$$

where y is the distance from the surface which is held at the fixed temperature T_0. The temperature at distance y asymptotes to its final value (T_0), though not in an exponential manner. A reduction $|T - T_0|$ by a factor of e^{-n} requires a period of $(y^2/4\kappa q_n^2)$ seconds, where q_n is defined by:

$$\text{erf} \, (q_n) = e^{-n} \quad (q_1 = 0.339, \quad q_2 = 0.120 \text{ etc.})$$

It will be assumed here that during its transit along the wall the air at position y spends a period of $y^2/4\kappa q_1^2$ seconds, so that its temperature anomaly relative to the wall will be reduced by a factor of about e. Thus,

$$T = \frac{L}{v} = \frac{y^2}{4\kappa q_1^2} \quad ,$$

or

$$y^2 = \frac{4\kappa q_1^2 L}{v}$$

Consider now the slab of air between the point y and the wall. Assume that its temperature is $(\delta T/2)^\circ$ C warmer (or cooler) than the average of the entire volume. The buoyancy force acting on a column of length L, of unit breadth is then $-gyL\delta\rho = (1/2) gyL\rho (\delta T/T)$. The only other force is the viscous stress at the wall, since at the location of the maximum velocity, there is no shear. Taking the gradient of velocity at the wall to be $2v/y$, as would be the case in a two-dimensional Poiseuille flow, the viscous stress along the wall, per unit breadth, is $2\eta vL/y$.

Hence,

$$\frac{1}{2} gyL\rho \frac{\delta T}{T} = \frac{2\eta vL}{y}$$

so that

$$v = \frac{gy^2}{4\nu} \frac{\delta T}{T}$$

where ν is the kinematic visocity of air. Substituting the earlier expression for y^2,

$$v^2 = \frac{g\kappa q_1^2 L}{\nu} \frac{\delta T}{T}$$

and

$$y^4 = \frac{16\nu\kappa q_1^2 L}{g} \frac{T}{\delta T}$$

Taking $g = 10^3$ cm sec^{-2}, $\kappa = 0.22$ cm^2 sec^{-1}, $\nu = 0.15$ cm^2 sec-1, $L = 50$ cm, $q_1^2 = 0.115$, $T = 300°$K, $v^2 = 286 T$, and $y^4 = 0.9/\delta T$. Thus for δT in the range 0.01 to 0.1°C, as seems plausible under laboratory conditions, the estimate of v lies in the range 1/2 to 1-1/2 cm sec^{-1}, and that of y in the range 3 to 2 cm.

Experimental work by Prandtl (Reference 20) would indicate similar velocities, in the range 0.7 to 2 cm sec^{-1} under these conditions.

In considering the effect of convection currents on particle losses, it would appear that a perfectly steady and laminar circulation of air would have little effect on the rate of loss. The particle-depleted sheath of air lying close to the wall would remain there, effectively shielding the bulk of the gas from much further particle loss. Unsteadiness in the flow, however, is very likely to occur, and a simple way to model the loss of particles is to suppose that the particle-depleted air very close to the wall is replaced by unmodified air every T' seconds. If this is so, the particles out to a distance x will be largely removed, if $T' = x^2/4Dq_1^2$, where D is the diffusivity of the particles; thus, $x^2 = 4q_1^2 D T'$. It will be assumed that T' is equal to mL/v_x where v_x is the convective velocity at distance x from the wall. This is equivalent to supposing that the sheet of air of depth x clings to a wall until it has traversed a distance equal to m times L, a typical linear dimension of the container. The number m may be expected to be of order unity. The velocity at distance x, v_x is about $2vx/y$, since x is quite small compared with y. Thus,

$$T' = mLy/2vx$$

Combining the two expressions for T'

$$\frac{x^2}{4q_1^2 D} = \frac{mLy}{2xv},$$

or

$$x^3 = \frac{2mL\,Dy}{v}q_1^2$$

From the above,

$$\frac{x}{T'} = \frac{4q_1^2 D}{x}$$

$$= 4q_1^2 D\left(\frac{v}{2mLq_1^2 Dy}\right)^{1/3}$$

$$= \frac{2^{5/3}\,q_1^{4/3}\,D^{2/3}}{m^{1/3}\,L^{1/3}}\left(\frac{v}{y}\right)^{1/3}$$

But,

$$\frac{v^4}{y^4} = \frac{g^3 q_1^2 kL}{16\nu^3}\left(\frac{\delta T}{T}\right)^3$$

Hence,

$$\frac{x}{T'} = \frac{2^{4/3}\,q_1^{3/2}\,D^{2/3}\,k^{1/12}\,g^{1/4}}{m^{1/3}\,L^{1/4}\,\nu^{1/4}}\,\frac{\delta T}{T}^{1/4}$$

Substituting the same values as earlier, assuming $D = 10^{-5} \text{ cm}^2 \text{ sec}^{-1}$, an average value for cloud nuclei, and setting $m = 1$, this yields a value for x/T' of about $2 \times 10^{-4} (\delta T)^{1/4}$. If the area of the walls is $A \text{ cm}^2$, and the volume $V \text{ cm}^3$, the proportional loss of particles per second will be about $2 \times 10^{-4} A (\delta T)^{1/4}/V$. In a typical bag container, $A \approx 2 \times 10^4$, $V = 3 \times 10^5$, so that the loss rate would be $5 (\delta T)^{1/4}$ percent per hour. For δT in the range 0.01 to 0.1°C, this corresponds to a range of 2 to 3 percent per hour.

The result is fairly insensitive to the value chosen for m. The fair agreement with terrestrial observation (a total loss rate of about 5 percent per hour) may be fortuitous, but it gives some confidence to the prediction that the main cause of particle depletion is diffusion to the walls in the presence of convection currents, and that this loss will vary as

$$\left(\frac{g \delta T}{L} \right)^{1/4} .$$

Similar results are given by Levich (Reference 21) for diffusional flow in natural convection for the case of a vertical plate. In that case, the density changes were assumed to result from heterogeneous chemical reactions.

6.2.6 Acceleration Level (g-Level)

Ambient acceleration levels affect many aspects of the cloud physics experiments ranging from particle motion to convective circulation. Thus an evaluation of many of these factors discussed in this report depend on an estimation of the expected residual acceleration levels.

Acceleration levels present aboard the Space Shuttle Orbiter/Spacelab are due to drag, gravity gradient, and other orbital environments, to crew activities ranging from arm and leg motions through walking or exercise and to onboard machinery and propulsive devices. The acceleration envelope presented in Figure 6-10 encompasses these acceleration disturbance sources. In developing these data, linear, radial, and tangential accelerations were considered and the maximum values indicated.
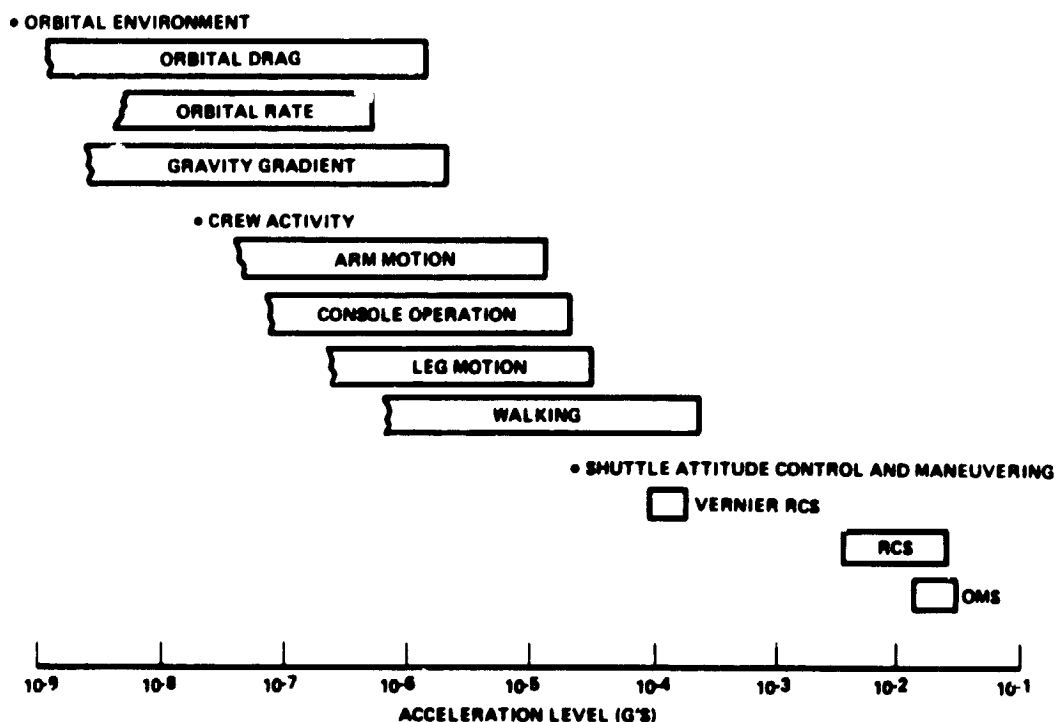
Figure 6-10. Shuttle/Spacelab Acceleration Levels

Representative numbers were assumed for the Shuttle/Spacelab. The Shuttle Orbiter with its Spacelab payload would weigh 250,000 lb. The OMS (orbital maneuvering system) with its two 6,000-lb engines performs altitude adjusting and rendezvous operations at 10^{-2} g. The RCS (reaction control system) with forty 900-lb$_f$ thrusters selectively activates various thrusters for body axis rotations and ranges from 10^{-3}g through 10^{-2} g. The vernier thrusters, six at 25 lb$_f$, in the RCS operated when quiescent periods are required yield disturbances in the 10^{-4} g level. Acceleration levels for crew activities are 10^{-4} g and less, whereas the orbital environments are 10^{-6} g and less.

The actual motion during an orbit was given in the Subsection 6.2.4.3.

Noting that most of the crew activity items are cyclic and often would average to zero over a specific period of time suggests that 10^{-4} g would be readily available while 10^{-5} to 10^{-6} may be available aboard Spacelab, for certain types of experiments.

6.2.7 Aerosol Transport

Aerosol losses while being transported through tubes result from thermal (Brownian) coagulation and velocity gradient coagulation. The former can be neglected for small transit times while the latter will become important at higher transport velocities.

The decrease in concentration (n) of an aerosol due to the diffusion toward the walls for laminar flow through a circular tube is given by the empirical formula

$$\frac{n}{n_o} = 0.819 \exp (-3.675\mu) + 0.097 \exp (-22.3\mu)$$

$$+ 0.032 \exp (-57\mu) + \ldots$$

where μ is the dimensionless number

$$\frac{DX}{R^2 \overline{U}}$$

and

n_o - initial concentration
R - radius of tube
X - length of tubing
D - diffusion coefficient of particles
$\overline{U}$ - the mean flow velocity on tube

as obtained by Gormley and Kennedy (Reference 22) in 1949. Since $\overline{U}$ has a $1/R^2$ dependence (for well developed Poiseuille flow), the diffusional losses can be reduced to an extent by using larger tubing. The larger the tubing however, the slower the mean velocity $\overline{U}$, and consequently the duration of aerosol in the tubing is longer.

The volume flow rate $\dot{Q}$ provides a coupling between the tube radius R and flow velocity $\overline{U}$

$$\dot{Q} = R^2 \overline{U}$$

Using this in μ gives

$$\mu = \frac{\pi D}{\dot{Q}} X$$

showing that the loss rate is an inverse function of flow rate and a linear function of distance X.

Losses can be decreased by increasing $\dot{Q}$ and/or decreasing X. As long as the flow is laminar, the loss is independent of tube radius for fixed $\dot{Q}$ and thus only a function of X. Special considerations must be given if there is turbulent flow, corners, or excessive shear.

Particles with radii (r) of 0.005 and 0.1 micron which have a diffusion coefficient (D) of 0.52×10^{-3} cm^2/sec and 0.22×10^{-5} cm^2/sec respectively were considered. Tubing sizes considered included R = 0.2 cm, 0.5 cm, 1.0 cm, 1.5 cm, 2.0 cm, 2.5 cm, and 3.0 cm with mean flow rates between 0.5 and 10.0 cm/sec. Figures 6-11 and 6-12 illustrate the effect of flow rate and particle size on loss rates for a representative tube of 1.0-cm diameter.

The equation and graphs apply only to straight sections of tubing. Additional losses which cannot be calculated occur at bends or other deviations from a straight tube. The losses at bends will in general be greater for the larger particles due to the larger inertia.

6.2.8 Radiation Pressure
Radiation pressure causes the movement of material as a result of the laws of conservation of energy and momentum during the interaction between radiation
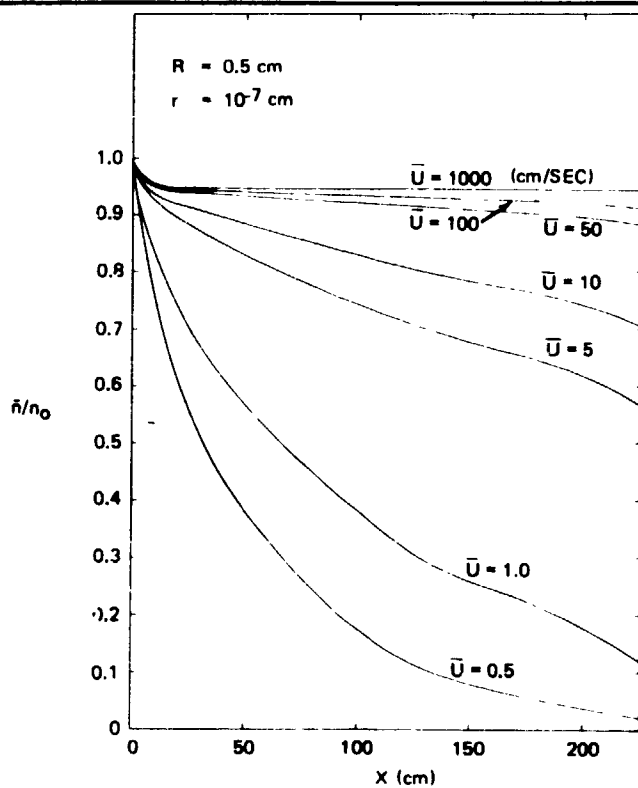
Figure 6-11. Aerosol Transport Losses (r = 5 x 10^{-7} cm)
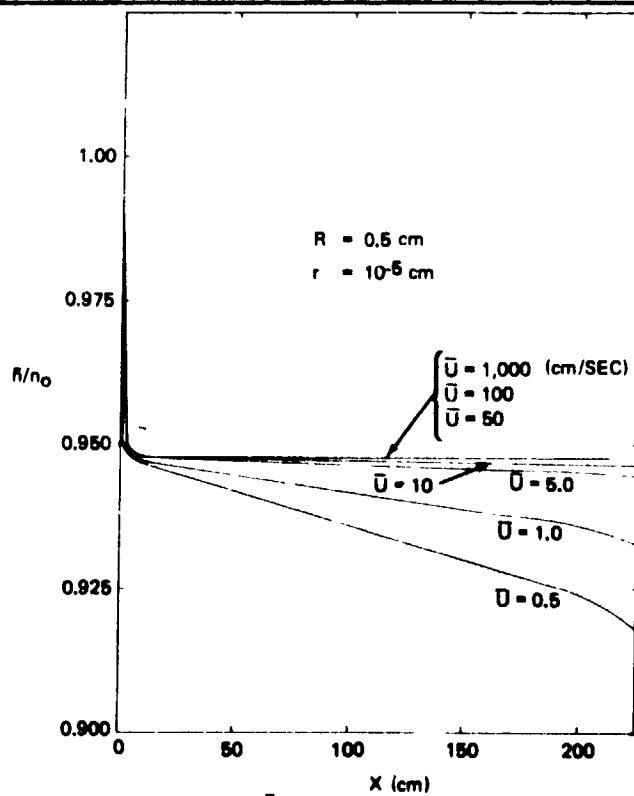
Figure 6-12. Aerosol Transport Losses (r = 10^{-5} cm)

and material where radiometric forces are neglected. The following evaluation estimates the optical power density required for motion control of particles with diameters below 100 micrometers.

Radiation pressure is given by (Reference 23)

$$F_{R.P.} = \frac{I\, 2\pi r^2 q}{C}$$

where

I = incident energy (watts/cm^2)

C = speed of light

r = radius of particle

q = fraction of light reflected back

The radiant power on a 1-micron diameter particle to move it at a velocity of 1 cm/sec is given by ($F_s = 6\pi\eta rV$, Stokes force associated with air drag):

$$(I\pi r^2) = \frac{F_s C}{2q} = \frac{6\pi\eta\, CrV}{2q}$$

For

$$\eta = 1.5 \times 10^{-4}\ \text{dynes-sec/cm}^2$$
$$q = 0.1$$
$$I\pi r^2 = 2.12\ \text{milliwatts}$$

where a change of units to the more familiar watts has been made. In application, the total beam would not be focused onto the particle and thus larger powers would be required in the ratio of total beam power to power striking particle.

Terrestrial laboratory investigations at Bell Labs has shown that glass spheres and liquid droplets can be very stablely supported for diameters up

to 50 μm using nonabsorbing laser power of around 1 watt. The manipulation of particles below 0.1 mm in a 10^{-3} g environment is very feasible.

6.2.9 Radiation Heating

Light beams (whether incandescent, flash, or laser), which are used to observe the cloud microphysics phenomena under investigation, can exert a disturbing influence on the experiment. Laser illumination is preferred for experiment observation because it is monochromatic, polarized, and nearly perfectly collimated. The chief influence of such illumination will be the heating of the bulk gas and/or water droplets under investigation.

The rise in the internal temperature of a water droplet illuminated by a low-intensity beam with visible wavelength is negligible. For a range of realistic conditions, the rise in temperature is of the order of 10^{-5}° K/sec. The following set of assumptions are used as an example:

He-Ne laser wavelength:	$\lambda = 0.6328$ μm
power output of laser:	$P_0 = 10^{-1}$ joules/sec (100 milliwatts)
radius of laser beam:	$R = 0.85$ cm
imaginary part of index of refraction of water at $\lambda = 0.6328$ μm:*	$Im(n) = 1.6 \times 10^{-8}$
absorption coefficient for water:	$\alpha = \dfrac{4\pi Im(n)}{\lambda} = 3.2 \times 10^{-?}/cm$
radius of the water droplet:	$r = 10^{-3}$ cm (10 μm)
specific heat of water:	$c = 1$ cal/gm/° K
density of water:	$\rho = 1$ gm/cm^3

The rise in the internal temperature of the water droplet** (when $\alpha r \ll 1$) is given by

$$\Delta T \simeq \frac{P_0}{4.186} \frac{r^2}{R^2} \frac{\alpha r \pi}{4} \left(c \frac{4}{3} r^3 \rho \right)^{-1} \text{° K/sec}$$

*The imaginary part of the index of refraction for water at 0.6328 μm and 25° C was taken from George M. Hale and Marvin R. Querry, Applied Optics, 12, 555 (1973).
**The quantities have the units given in the definitions. The units in parentheses are explanatory.

$$= 4.5 \times 10^{-2} \frac{P_0 \alpha}{R^2}$$

$$= 2 \times 10^{-5} \text{ °K/sec}$$

As can be seen from this equation, ΔT is independent of the droplet radius. This result is dependent on the condition $\alpha r \ll 1$.

The rise in temperature of the gas illuminated by the 100 milliwatt He-Ne laser is also negligible. For a typical illuminated volume of gas composed air, saturated water vapor, and aerosols, we can estimate an upper bound on ΔT of about 10^{-5} °K/sec. To do this, we use a total attenuation coefficient (including both elastic and inelastic scattering) which was obtained from experimental data on air with water vapor and naturally occurring aerosols. *

total absorption coefficient: $\quad \alpha_g \simeq 7 \times 10^{-7} \text{ cm}^{-1}$

specific heat of the gas: $\quad c_p \simeq 0.24 \text{ cal/gm/°K}$

density of the gas: $\quad \rho_g \simeq 1.3 \times 10^{-3} \text{ gm/cm}^3$

volume of gas: $\quad \pi R^2 \ell$

The rise in temperature (when $\alpha \ell \ll 1$) is given by

$$\Delta T \simeq \frac{P_0 \alpha_g \ell}{4.186 c_p \pi R^2 \ell \rho_g} = 2.4 \times 10^2 \frac{P_0 \alpha_g}{R^2}$$

$$\Delta T \simeq 2 \times 10^{-5} \text{ °K/sec}$$

The total attenuation coefficient was taken from an average of seven different experiments at an altitude of 1 km for real atmospheric conditions. A rough estimate for the corresponding concentration of 2-μm aerosol particles is about 100 ± 50 particles per cm^3. The α we have used includes the elastic Rayleigh scattering attenuation coefficient and also the effect of any water

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*This value of α_g was taken from L. Elterman, Air Force Cambridge Research Laboratory, report 0155 (1968), p. 34, for an altitude of about 1 km and 15°C.

vapor (saturated or otherwise) which is present. Under most conditions, the experiments were not performed on water-saturated air. However, the effect of the water vapor will be small. At 100 percent relative humidity, water clusters will have nucleated only on the impurity aerosols and are in effect no more dense than the aerosol particles themselves.

Subject to the above considerations, we can limit the rise in temperature of the illuminated gas to no more than 10^{-5} °K/sec. Thus the heating effect of the 0.6328-μm laser beam when used for illumination will be negligible for both the gas and the water droplets.

6.2.10 Air Ionization

Ambient ionization levels determine the charge decay rates from charged particles. Thus air ionization levels within the zero-gravity CPL chambers must be considered when developing techniques and experiments dealing with highly charged particles. First an estimate is determined for the ionization rates expected in a Spacelab environment. Next the ionization levels are related to particle charge relaxation times.

Free-space galactic cosmic ray doses are generally calculated to fall in the range from 3 to 13 rad yr^{-1} (Schaefer; [Reference 24]; Weidner [Reference 25]) including a factor of 2 or so variation over the solar cycle. Using recent spectral measurements (Kinsey [Reference 26]; Balasurbrahmanyan [Reference 27] et al.), Langley (Reference 28) has calculated the relative dose in 200-nm altitude orbits of various inclinations for the interior of a detailed space station configuration.

Since the rad is 100 ergs gm^{-1}, and assuming 35 eV per ion pair production in air, the numbers of ion pairs produced by galactic cosmic rays in the same orbits for the extreme values of free space dose mentioned above are given in Table 6-2. These numbers are appropriate for all reasonable space-craft wall thicknesses. Recent measurements have tended to substantiate these results. Direct measurements on Skylab yielded inconclusive results, but do not indicate higher ionization rates than those shown (R. W. Langley, private communication).

Table 6-2

IONIZATION RATE AS FUNCTION OF ORBIT INCLINATION

| Inclination (deg) | Fraction of Free-Space Dose | Number of Ion Pairs $gm^{-1}sec^{-1}$ | |
		Minimum	Maximum
0	0.014	2.4×10^3	1.1×10^4
30	0.023	4.0	1.7
45	0.043	7.4	3.2
60	0.132	2.3×10^4	1.0×10^5
75	0.245	4.3	1.9
90	0.264	4.6	2.0

A number of phenomena (e.g., surface double layer and air motion) must be considered to fully account for the droplet charging and charge equilibrium distribution of single or multiple droplets in a low-gravity environment. Considerating only droplet charging by diffusion provides an estimate of the affects resulting from the variation in ion production rates as will occur within the zero-gravity CPL. These effects can then be compared with those conditions which normally occur in a terrestrial laboratory.

A first order estimate can be obtained by using the work of Gunn (Reference 24). Using the reasonable assumption that $Nu = N_+u_+$ is approximately equal to N_-u_- ($N_{\pm}$ is the respective positive and negative charge density at a distance from the droplet(s); $u \pm$ respective charge mobility) provides the droplet charge as a function of time

$$Q = Q_o [1 - \exp(-4\pi eNut)]$$

where Q_o the equilibrium value of charge given by

$$Q_o = a \frac{kT}{e} \ln \frac{N_+U_+}{N_-u_1}.$$

Thus, the effective charging time, τ, is

$$\tau = 1/(4\pi e\ Nu).$$

The terms as defined for terrestrial conditions are:

$N_{\pm}$	=ambient charge density	$300 - 500$ ions/cm^3
u	=ion mobility (mean value)	1.9 cm^2 V^{-1} sec^{-1}
u_-/u_+	≈ 1.4	
t	time in seconds	
a	droplet radius in cm	
k	Boltzmann constant	
e	unit charge	

The equilibrium time must be considered as an approximation because the charging mechanism normally removes ions from the region outside the droplet and thus systematically decreases the ambient ion density, N, as a function of time (assuming a realistic constant ion production source). Thus the equilibrium charge density N is also a function of droplet density. For example, for ten ion pairs per cubic centimeter per second, the expected ion density will approximate 3400 ions/cm^3 while if 300 droplets/cm^3 with 10^{-3} cm radius are present, this ion density will be reduced to only 70 ions/cm^3.

Although the equilibrium distribution of charge on a cloud of droplets is not a function of the ionization level, the time to obtain equilibrium is a function of this ionization level. Thus for experiments dealing with highly charged droplets (charge effects on ice and droplet collisions with charges greater than a few tens of unit charges), the ionization level will control the rate at which this charge will be neutralized and thus control the time frame in which the experiment must be accomplished. Near the earth's surface, the time constant is around 10^3 sec (τ_e) while under worst case conditions in an earth orbit (Table 6-3) this would be reduced to 10^2 seconds or less. Table 6-3 shows that selected periods of time could provide more than 10^3 sec while mean anticipated conditions would result in a time constant between $\tau_e > \tau_o > \tau_e/5$ (noting that the time constant is inversely proportional to the ion concentration).

Table 6-3

AMBIENT IONIZATION LEVEL

Orbit Inclination (deg)	Ionization Level		
	Number of Ion Pairs Sec^{-1} cm^{-3}		
	Spacelab		
	Min	Max	Terrestrial Nominal
0	3	14	10
30	5	22	10
45	10	42	10
60	30	130	10

The ionization level within a 200-mile earth orbit will only have an appreciable effect on those experiments involving highly charged droplets. The consequence would be a faster charge decay and this effect could be minimized by appropriate selection of orbit inclination, orbit position, and solar activity level. All other experiments would respond electrically as in a terrestrial laboratory thus requiring the usual experimental precautions and procedures. Gunn (Reference 30) provides an estimate of the expected charge distribution on a cloud of droplets.

There are several relevant references concerning particle charging in an ionized environment. The work by Takahashi (Reference 31) includes empirical measurements on the effects of water surface double layer and of evaporation (condensation) vapor pressure while the two papers by Borilov and Sidunov (Reference 32) provide theoretical analysis.

6.3 ENGINEERING ANALYSIS

The formulation of the laboratory concept was based on supportive engineering analyses. For the conduct of manual orbited experimentation, particular emphasis was placed on contamination, expendable quantities, thermal control, and optics design features. These analyses are presented in the following sections. Additional trade studies are presented in appropriate sections of this report.

6.3.1 Contamination Assessment

Three classes of contamination have been evaluated as to their effect on the CPL design and, where applicable, on Spacelab subsystems. These classes are not in every respect independent of each other, and optimization of the overall CPL design will require evaluation of the individual subsystems and their interactions. The classes are defined as:

Class 1. Contamination external to CPL subassemblys and hardware and generated either by the CPL equipment or by the Spacelab equipment or environment.

Class 2. Internal cleanliness of CPL subsystems. This class is confined to either open or closed subassemblies that are in contact with the expendable working fluids and includes the cloud chamber assemblies.

Class 3. Purity of all working fluids including air, water, and sample gases.

To provide a generalized perspective of the CPL contamination aspects a summary of terrestrial laboratory cleanliness experience factors are presented.

6.3.1.1 Class 1 — External Contamination

Contamination generated by the CPL and Spacelab may affect either or both assemblies. Contaminant sources assessed in this study are:

A. Thermal control system leakage

B. Acoustic fields

C. Electromagnetic fields

D. Vibration

E. Spacelab atmosphere

F. Ambient pressure/temperature variations

Thermal Control System Leakage

Only water is used as a coolant in either the Spacelab or the CPL cloud chamber cooling system. (Pure water is also used as one of the CPL experimental fluids.) Based on the Skylab Orbital Workshop experience, the fluid systems can be designed and assembled with almost nonexistent leakage, and the leakage that does occur can be absorbed by the Spacelab dehumidification systems. Corrosion inhibiters will be used, but at minute leak rates no problems are expected.

Ammonia heat pipes may be used in conjunction with cloud chambers assemblies. Ammonia is a toxic fluid, but the total amount is small, and relative to the Spacelab volume, will not approach the industrial threshold limit value for 8-hour exposure. Moreover, the ammonia will be quickly absorbed by the Spacelab dehumidifier and lithium hydroxide canisters. No problem is expected.

Experiment fluids are essentially terrestrial air with minute amounts of contaminants added. Total quantities of the fluids are small and the Spacelab atmosphere revitalization system can remove the trace contaminants due to leakage or even catastrophic failure. No problem is anticipated.

Acoustic Fields and Vibration

Both acoustic and vibration fields can impact experiments by impairing ability to optically observe partial activity. Analysis is required to develop the maximum, tolerable levels.

Electromagnetic Fields

The CPL will be designed to meet the electromagnetic compatibility (EMC) requirements of MIL-E-6051D and MIL-STD-461A, which are imposed on Shuttle and Spacelab. These requirements and criteria include, but are not limited to grounding, electrical bonding, interface wire types/shielding, and filtering.

Spacelab Atmosphere

The Spacelab and its payloads will be designed to a 100,000 cleanliness level. Trace contaminants that may affect this cleanliness level, and originating within CPL, may result from leakage, outgassing, etc. These contaminants will be monitored by onboard equipment and removed by the atmosphere revitalization system. No effect on equipment or on optical viewing devices is expected; nor will other Spacelab payloads be affected. Heat rejection of CPL equipment is low (800 watts) and imposes no appreciable load on the Spacelab ECLS.

Ambient Pressure/Temperature Fluctuations

Spacelab pressure is controlled to 14.7 ± 0.2 psia; temperature is controlled to 22 ± 4°C. Pressure of CPL experiments is controlled by CPL regulators and is unaffected by Spacelab pressure changes. Based on Skylab Orbital Workshop experience, the rate of change of the Spacelab ambient temperature will be very small and will have no effect on the control of experiment sample humidity and temperature over the 8 hour, or less, experiment period. Additional damping can be expected because of the mass (thermal capacitance) of the experiment equipment.

6.3.1.2 Class 2 — System Internal Cleanliness

Many cloud chamber experiments depend on the effects of suspended particles with known size and mass distribution. Results may be masked or invalidated by effects of quantities of contaminants of unknown character. Initial cleaning of the assembled CPL to a 100 class product cleanliness level (currently the aerospace industry precision cleaning standard) can statistically result in about the same number of residual contaminating particles in a test sample as their are test nuclei. Experience and tests indicate, however, that loose particles are removed by the cleaning methods, and particles remaining after cleanliness verification are adhering to the internal surfaces and will not materially affect sample quality since they will only slough off due to flow of fluids, vibration, etc. Since launch will be the only significant source of vibration following cleaning, it is recommended that the system be subjected to a prepurge following CPL activation to remove launch-generated particulates.

Air and sample gases can also be carriers of contaminants and will affect both test specimens and hardware through which they flow unless also filtered during the storage tank filling operations. These gases will also be filtered prior to mixing of test samples, but it should be recognized that 0.1 micrometer is currently about the best filtration that can be achieved, and this is in the range of nuclei to be generated for experimentation.

Relative to contamination of equipment by test gas samples, evacuation, purging and flushing of all affected equipment will follow each test, whenever necessary. However, procedures will have to be developed and their efficiencies determined by test in order to fully evaluate their effectiveness.

6. 3. 1. 3 Working Fluid Purity

As previously noted (Subsection 6.3.1.2), air and sample gas cleanliness is a factor in the gradual degradation of system cleanliness as well as a factor in the purity of the test sample. These fluids are essentially inert, and their effects are principally those associated with entrained contaminants.

Super-pure water may eventually be proven to be a requirement for successful cloud physics experimentation. The following factors should be considered before the requirements are finalized.

The CPL design should be consistent with the level of water purity. Materials should be used which will not react with water to avoid unwanted contaminants. The CPL initial cleanliness should be consistent with the level of water purity. Residual system contamination will lower water quality regardless of its initial purity.

The GSE used to produce water and fill the CPL storage tank should be consistent both as to material selection and cleanliness with the necessary level of water purity.

The cloud chambers will function essentially open loop and bacteria growth can occur. Procedures to prevent bacteria growth should be developed.

System components such as valves are a potential source of contamination unless specially designed and developed for the application.

Super-pure water can be produced but at high cost. Considering the probability that its quality cannot be retained from initial distillation to final usage, a compromise in water requirement with system design requirement should be considered before the final water specification is released.

6.3.1.4 Terrestrial Laboratory Cleanliness Experience Factors

The diverse experiment areas in cloud microphysics coupled with the scattered locations of the research units have precluded formulation of a standardization of cleaning procedures and cleanliness specifications. A general working group is required to provide specific and quantitative specifications that would be applicable to the multi-experiment ZG CPL program.

The following comments can be made concerning the qualitative aspect of the cloud physics cleanliness requirements.

Gas

The gas used during the experiments will contain normal atmospheric constituents. Sometimes a single component gas such as nitrogen would be used as compared with the normal oxygen/nitrogen combination existing in normal commercial bottles of air. Two specific contaminants of this air have been delineated, (a) gases, and (b) particulates.

Organic vapors from such sources as waxes, oils, perfume, terpenes (e.g., from tape adhesive) and plasticizers from most soft plastics will cause undesirable effects on many of the cloud physics experiments. Laboratory usage has indicated that air filtering through activated charcoal will eliminate most of these organic vapors.

Particulates can for the most part be removed by "depth" type filters. Such paper, fiber glass and cotton filters exist which possess filtration efficiencies of 99.997% for DOP particles above 0.3 μm. These "depth" filters also collect much of the particulate matter well below the absolute cutoff by diffusion and electrostatic attraction between the particles and the filter media. Recent evidence has indicated that the thin membrane filters do not collect the sub 0.1 μm particles nearly as efficiently as has been thought in the past. Some care must be made in filter selection but filters do exist which will satisfy the "in-operation" cleanliness requirements.

Fluids

Well distilled water using several distillation cycles with standard procedures to avoid collection of the high vapor pressure contaminants at the start of

distillation and the resulting concentrated lower vapor pressure materials toward the end of the distillation process are all that are ne ᴗ sary. Levels of metal ions and atmospheric gases resulting from normal care during distillation are not detrimental to most of the cloud physics experiments as are potential organic contaminations. Some chemical processing as with potassium permanganate may be necessary to remove organic matter from the water.

Deionized water is not recommended because it contains large quantities of those types of organic impurities that must be avoided.

Component Cleaning

The purpose of the cleaning procedure is not only to remove dust particles and dirt in the usual sense from the chamber and components surfaces but also to remove organic films from the surfaces. Ordinarily most organic solvents contain fairly large amounts of oil, paraffin, etc., all of which are deleterious to cloud chamber operation. Acetone has been used successfully for the initial cleaning. Other acceptable solvents may exist. Final cleaning with condensing steam may be required to assure the surface cleanliness level. A final test for surface cleanliness is observation of the way the water film dries from the surface. The desired result has been obtained on glass when water sheets off all surfaces and a continuous film remains and tends to dry evenly. A dummy glass plate may be used as a representative test surface in the cleaning of CPL components.

For those experiments where cleanliness is critical the appropriate chamber components should be dismantled and cleaned after each mission. Special attention should be given to keeping the optical surfaces clean. Flushing of the plumbing would probably be an acceptable procedure.

Materials

Cloud physics work has identified several materials that are not acceptable while a few materials have been used routinely with no visable detrimental affects.

The following are examples of materials that should not be used.

- Soft plastics often give off the plasticizer. Tygon is an example of a tubing that is not acceptable. Care should be taken not to cover sensitive equipment with plastics that give off these vapors.
- Terpenes, a component in the adhesive of tapes has been found to generate Aitken nuclei and thus should be avoided.

The following are a few materials that have been widely used and are deemed acceptable.
- aluminum
- butyl rubber
- polyethylene
- aluminized mylar
- stainless steel
- teflon

The above list is not exhaustive. A general criteria that should apply to the selection of materials is avoidance of materials that outgass over the working pressure range of the CPL. Usual considerations for material corrosion resistance under high humidity conditions must also be given.

6.3.2 Air and Water Quantity Requirements

6.3.2.1 Air Quantity

The quantity of air used as the principal constituent of a test gas sample has been derived from the requirements for experiment operations, clearing purges, and cleansing purges for each experiment class.

The following assumptions were generated for the analysis:
A. Number of daily fills of the humidification chamber and of nuclei generator is two each.
B. Number of daily cleansing purges of subsystem equipment is two.
C. Cleansing purge consists of 20 flushes of equipment at 0.25 atmosphere.
D. Clearing purge is performed between each experiment event = number of events minus one.
E. Clearing purge consists of 5 flushes of equipment at 0.25 atmospheres.

F.   Number of experiment events per day per class

$$= \frac{8 \text{ hours of experiment time per day}}{1.5 \text{ x (nominal event time per event)}}$$

The following data were used to complete the analysis.

Figure 6-13 and layouts of the CPL define the maximm humidification chamber (HC) and nuclei generator assembly (NGA) dimensions.   A 0.3 m^3 volume and L/D of 2.5 has been selected for each.

Figure 6-14 defines the nominal experiment time by class.

Table 6-4 summarizes the results of the analysis using Figure 6-14 and assumptions 1, 2, 4 and 6.

Table 6-5 summarizes equipment volumes by experiment class.

Table 6-6 and Table 6-7 summarizes the analysis results by experiment class using Table 6-5 and assumptions 1 through 6.

As a consequence of the above analysis, the maximum air volume requirement has been determined to be 45.9 m^3 at standard atmospheric conditions.   Four Spacelab bottles with a total usable volume of 57.9 m^3 have been selected for gas storage.

6.3.2.2   Water Quantity
The water requirement for the CPL is based on usage of diffusion cloud chambers wetted surfaces, the droplet/aerosol generators and by the humidifier for sample gas humidification.

The following assumptions and estimates were used in determining the maximum water usage requirement:
    A.   Cloud chamber requirements are a function of wetted area and a 1.0-mm film thickness.
    B.   Vapor transport between upper and lower wetted surfaces consumes a water volume equal to wetted surface volume.
    C.   Water flow to maintain clean surfaces within the CFD chamber is 1.0 ml per minute of experiment operation.
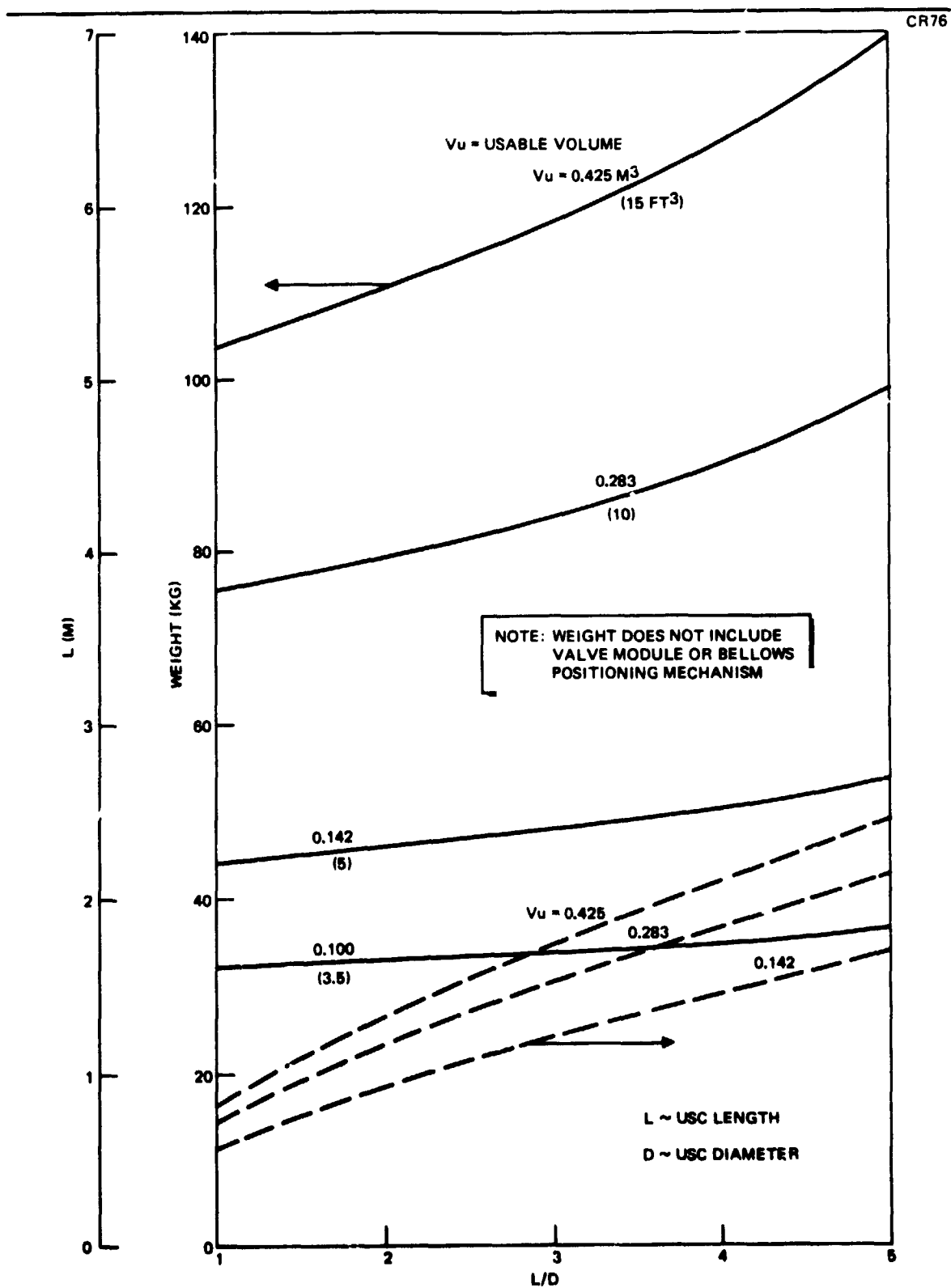
Figure 6-13. Humidification Chamber Weight
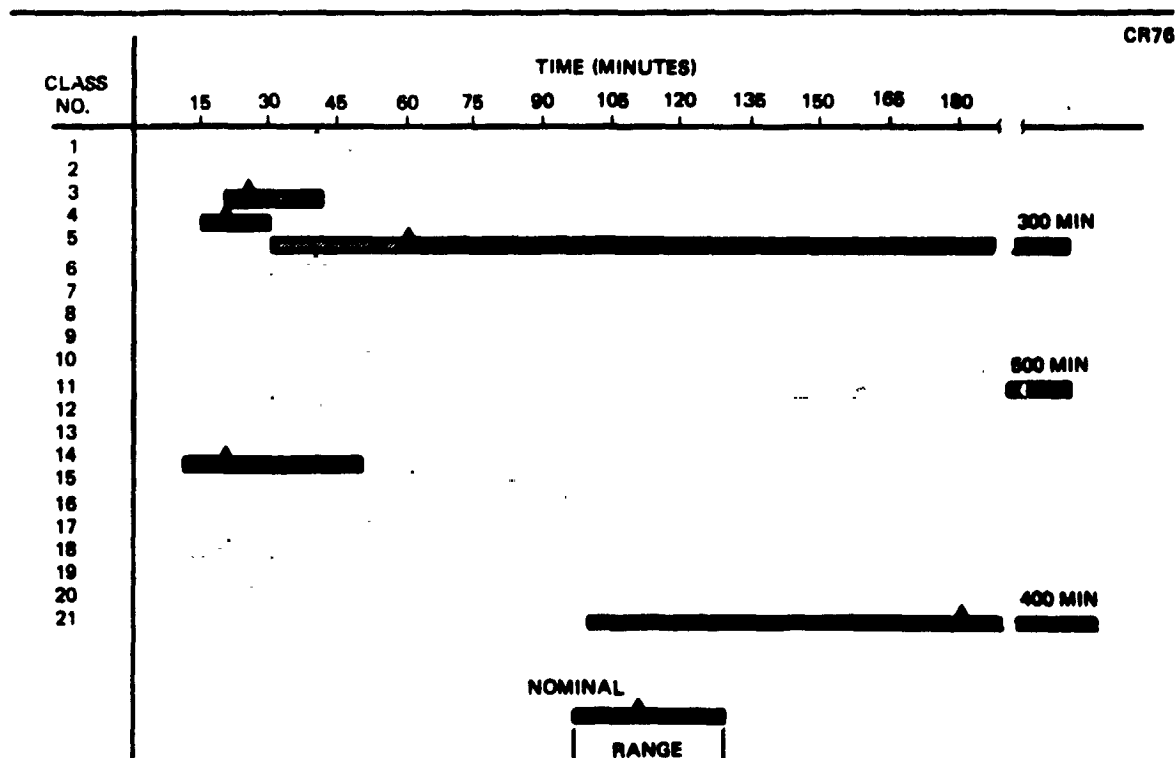
Figure 6-14. Effective Experiment Observation Times

D. Water volume required by the droplet/aerosol generators is 250 ml.

E. Fifteen percent of the total stored air is humidified to 100 percent relative humidity.

F. Water line volume is 100 ml.

Table 6-8 summarizes by experiment class the analysis results using the above assumptions. A maximum requirement of 1.582 liters has been established. To provide adequate reserve a single 2.0 liter, positive expulsion water tank has been selected.

6.3.3 Cloud Chamber Thermal Design

The CPL cloud chambers have thermal control requirements that include temperature control in the range of -60°C to +35°C. For the largest portion of the range (below +10°C), the Spacelab water loop temperature sink is

'e to provide either temperature control or heat removal capability.

Table 6-4

EXPERIMENT CLASS EVENTS AND OPERATIONS
REQUIRING SAMPLE GAS

Experiment Class	Nominal Experiment Observation Time (min)	Single Event Time (min)	Event/ Day (Typical)	Number Experiment Sample Gas Fills	Number of Clearing Purges	Number of Cleansing Purges
1	40	60	8	2	7	2
2	50	75	7	2	6	2
3	25	37.5	13	2	12	2
4	20	30	16	2	15	2
5	60	90	5	2	4	2
6	40	60	8	2	7	2
7	40	60	8	2	7	2
8	30	45	11	2	10	2
9	50	75	7	2	6	2
10	50	75	7	2	6	2
11	60	90	5	2	4	2
12	30	45	11	2	10	2
13	60	90	5	2	4	2
14	20	30	16	2	15	2
15	60	90	5	2	4	2
16	30	45	11	2	10	2
17	45	67.5	7	2	6	2
18	20	30	16	2	15	2
19	20	30	16	2	15	2
20	25	37.5	13	2	12	2

Table 6-5

CLOUD PHYSICS LABORATORY EQUIPMENT
ESTIMATED FLOW VOLUMES

Experiment Class	(PC) Primary Chamber/Volume (m³)	(USC) Humidification Chamber Volume (m³)	(NGA) Nuclei Generator Assembly Volume (m³)	(ECA) Expansion Control Assembly Volume (m³)	(SL) Subsystem Line Volume (m³)	Total Volumes (m³)
1	(CFD) 0.0045	0.3	0.3		0.2	0.8045
2	(SDI) 0.125					0.8045
3						
4						
5						
6						
7						
8						
9						
10						
11						
12	(E) 0.0318			0.2		1.0318
13						
14						
15						
16	(G) 0.027					0.827
17						
18						
19	(SDL) 0.0027					0.8027
20						

Table 6-6

DAILY SAMPLE GAS VOLUME REQUIREMENTS

Experiment Class	Daily Expt Sample Gas Fills	Daily Expt Sample Gas Fill Volume (m³)	Daily Expt Sample Gas Volume (m³)	Number of Daily Clearing Purges	Daily Clearing Purge Volume (m³)	Daily Clearing Gas Volume (m³)	Daily Number of Cleansing Purges	Daily Cleansing Purge Volume (m³)	Daily Cleansing Gas Volume (m³)
1	2	0.60	1.2	7	0.0645	0.54	2	0.5045	5.045
2				6	0.07125	0.51		0.5125	5.125
3				12		1.03			
4				15		1.28			
5				4		0.34			
6				7		0.60			
7				7		0.60			
8				10		0.86			
9				6		0.51			
10				6		0.51			
11				4		0.34			
12				10	0.0918	1.10		0.6318	6.318
13				4		0.44			
14				15		1.65			
15				4		0.44			
16				10	0.087	1.04		0.527	5.27
17				6		0.63			
18				15		1.57			
19				15	0.0627	1.13		0.5027	5.027
20	2	0.60	1.2	13	0.0627	0.98	2	0.5027	5.027

Notes

Clearing Purge = 5 x Volume of 1/4 atmosphere = 5/4 x Volume

Clearing Purge Volume = Chamber Volume + portion of SL (assumed as 0 06 m³)

Cleansing Purge = 20 x Volume at 1/4 atmosphere = 5 x Volume

Cleansing Purge Volume = Chamber Volume + 1/2 (USC + NGA + EC* Volume) + SLV

*when in use

Table 6-7

MISSION SAMPLE GAS REQUIREMENTS

Experiment Class	Daily** Experiment Sample Gas Volume (m³)	Daily** Clearing Gas Volume (m³)	(grouped)	Daily** Total Gas Volume (m³)	5 Day** Total Sample Gas Volume (m³)	Storage Volume (m³)	Gas Sample Weight (lb)	Sample* Usage Rate lb/hour
1	1.2	0.54	5.05	6.79	34.9	1.77	94.29	2.36
2		0.51	5.13	6.84	34.2	1.71	92.40	2.31
3		1.03		7.36	35.8	1.84	99.42	2.49
4		1.28		7.61	38.1	1.91	102.93	2.57
5		0.34		6.67	33.4	1.67	90.23	2.26
6		0.60		6.93	34.7	1.74	93.75	2.34
7		0.60		6.93	34.7	1.74	93.75	2.34
8		0.86		7.19	36.0	1.80	97.26	2.43
9		0.51		6.84	34.2	1.71	92.40	2.31
10		0.51		6.84	34.2	1.71	92.40	2.31
11		0.34		6.67	33.4	1.67	90.23	2.26
12		1.10	6.32	8.62	43.1	2.16	116.44	2.91
13		0.44		7.96	39.8	1.99	107.52	2.69
14		1.65		9.17	45.9	2.30	124.00	3.10
15		0.44		7.96	39.8	1.99	107.52	2.69
16		1.04	5.27	7.51	37.6	1.88	101.58	2.54
17		0.63		7.10	35.5	1.78	95.91	2.40
18		1.57		8.04	40.2	2.01	108.60	2.72
19		1.13	5.03	7.36	36.8	1.84	99.42	2.49
20	1.2	0.98	5.03	7.21	36.1	1.81	97.53	2.44

(Note: The Daily Experiment Sample Gas Volume is shown by an arrow spanning all rows as a constant value of 1.2 m³. The "(grouped)" clearing values — 5.05; 5.13 for classes 2–11; 6.32 for classes 12–15; 5.27 for classes 16–18; 5.03 for class 19; 5.03 for class 20 — are indicated with bracketing lines in the Daily Clearing Gas Volume area.)

*Based on 40 experiment hours

**At 1 atmosphere

Table 6-8
CPL MISSION WATER VOLUME USAGE

Experiment Class	Cloud Chamber Wetted Surfaces Water Volume (cm³)	Vapor Transport Water Volume (cm³)	Droplet/Aerosol Generators Water Volume (cm³)	Humidification Water Volume (cm³)	Water Line Volume (cm³)	Total* Water Volume (cm³)
1	890 (CFD)	90	250	252	100	1582
2	125.6 (SDI)	125.6				853.2
3						
4						
5						
6						
7						
8						
9						
10						
11						
12	0	0	250	250	100	602
13	125.6 (SDI)	125.6				853.2
14	0	0				602
15	17.6 (SDL)	17.6				637.2
16						
17	125.6 (SDI)	125.6				853.2
18						
19	17.6 (SDL)	17.6				637.2
20	17.6 (SDL)	17.6				637.0

* Based on 40 experiment hours

Based on experiment timeline requirements and reliability considerations, a configuration using thermoelectric modules has been selected to provide temperature control below +10°C.

The following assumptions were used in developing the thermoelectric requirements:

A. CPL can reject a maximum of 150 watts at +7°C to the Spacelab.

B. Cloud chamber heat load is based on:

 1. Ambient environment = 22°C

 2. Internal environment = -40°C

 3. Two glass view windows 50 mm diameter, 5 mm thick

 4. Polyurethane foam insulation

$$k = 0.14 \frac{Btu \ in.}{hr \ of \ +2° \ F}$$

 5. Inside chamber dimensions = 400 mm x 100 mm

 6. Insulation thickness = 60 mm

Cloud chamber cooling requirements were established by:

A. Calculating the steady state heat load on a typical cloud chamber using polyurethane foam for insulation.

B. Selecting an existing thermoelectric module with a heat pumping capacity two times larger than the calculated steady state heat load to allow for rapid cool down.

C. Calculating the transient performance to determine the time required to reach operating temperatures.

D. Sizing the heat storage device to adsorb excess heat (≥150 watts) during transient operation below -37°F.

Analysis indicates that for a cloud chamber heat load of 22 watts (calculation based on assumption 2, above), ten two-stage thermoelectric modules (TEM) are sufficient to allow for continuous chamber operation at -37°F. Figure 6-15 shows TEM steady state performance and Figure 6-16 shows chamber chilldown time.

Continuous operation at less than -37°F is not possible without exceeding Spacelab heat-rejection capability. However, transient operation using a
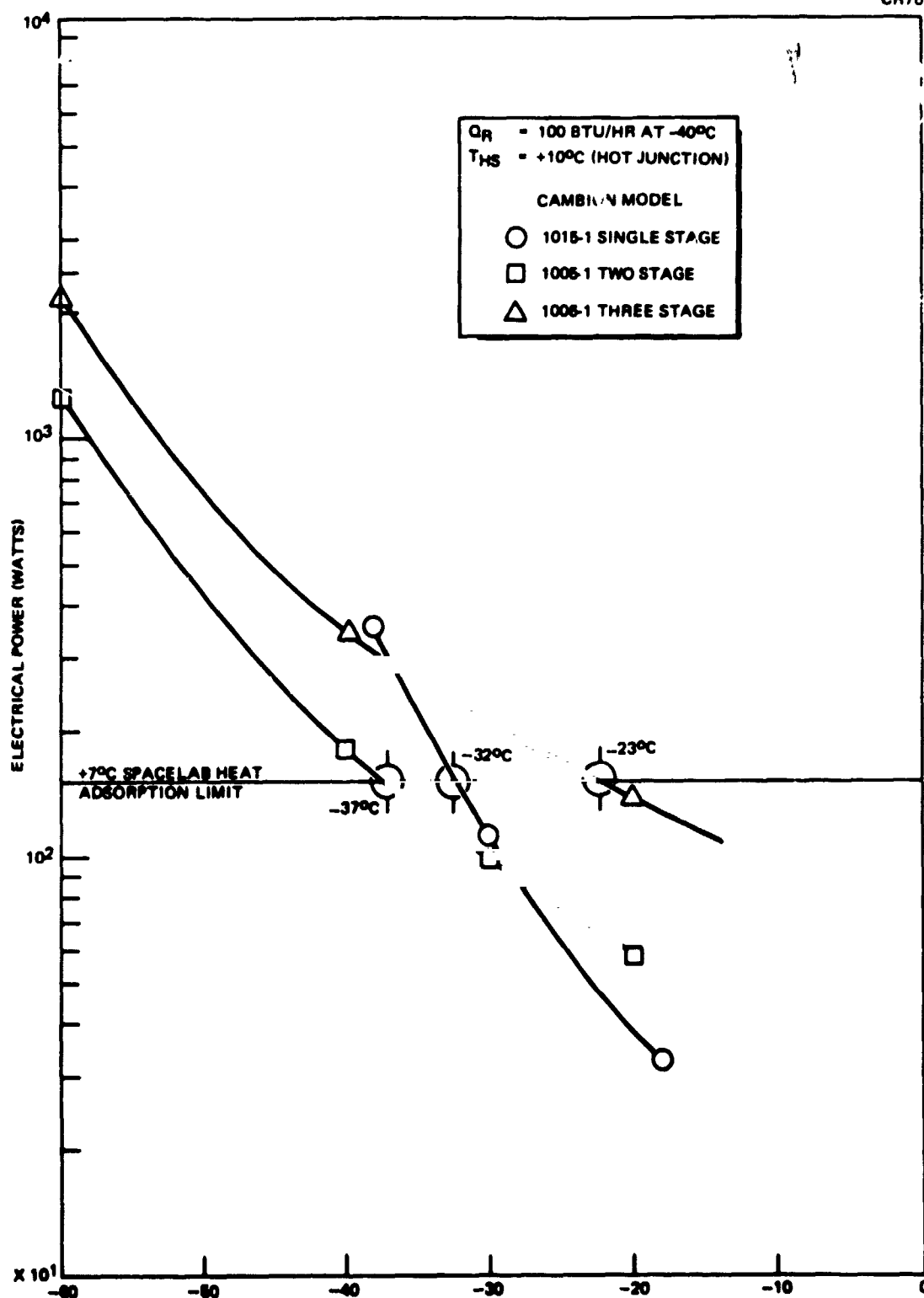
Figure 6-18. Steady-State Thermoelectric Module Performance
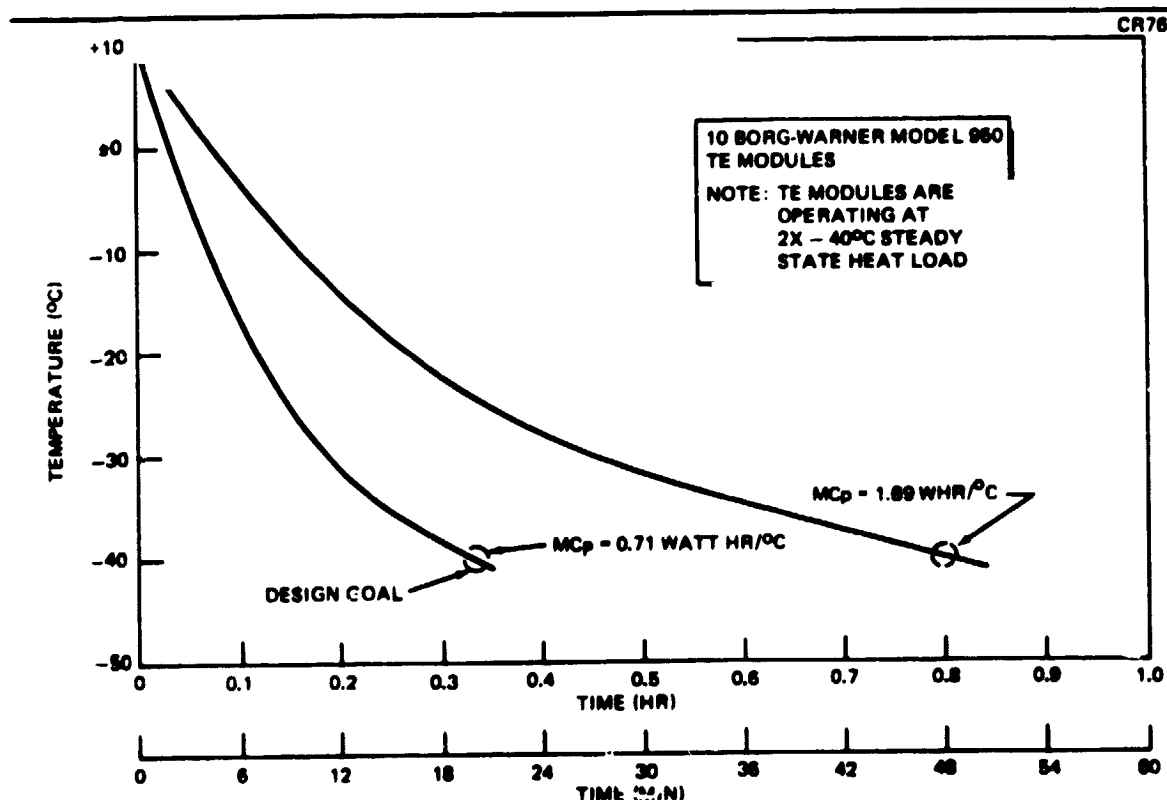
Figure 6-16. Static Diffusion Ice Chamber Internal Wall Temperature Response

rechargeable phase changing material is possible. N-pentadecane $(C_{15}H_{32})$ is a candidate material since it phase changes at 9.9°C. The amount of material (10 kg) was calculated based on an assumed requirement for 1 hour of operation at -50°C. At -40°C there is a capability for 6 hours of operation before the phase change material is completely melted.

Figure 6-17 shows the time to refreeze the phase change material as a consequence of steady-state operation of the cloud chamber at temperatures above -37°C.

6.3.4 Cloud Chamber Optical Requirements

The optical requirements to conduct the experimentation identified was evaluated in support of the optical and imaging devices subsystem equipment definition. Evaluations were conducted for chamber visual access, focal range, lighting, viewports, distortion calibration, data management requirements, optical interactions, holographs, resolution and special optical requirements. The following sections detail the results of those evaluations.
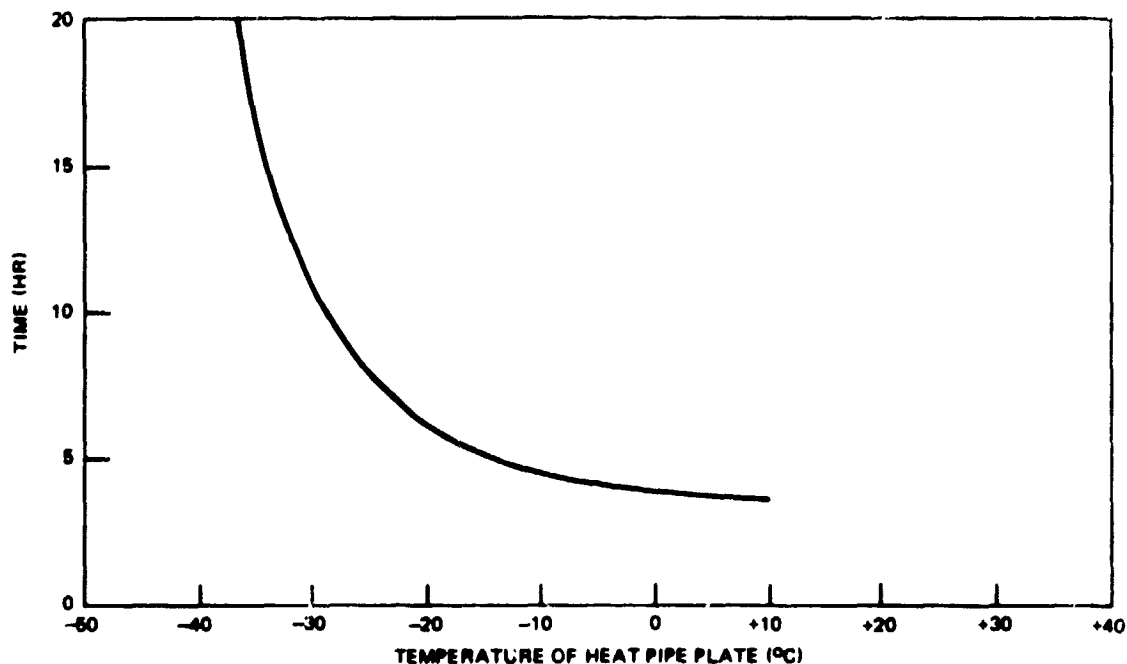
Figure 6-17. Phase Change Material Refreeze Time for 10 KG of $C_{15}H_{32}$

6. 3. 4. 1 Chamber Visual Access

Four of the five experiment chambers require visual access to permit observation and recording of the experiment events occurring within the chamber. This access is needed for illumination of the interior and to pro- vide a magnified view for the astronaut scientist's visual observations a . both video and film cameras record the events. The viewports must be large enough to allow the desired field of view but not large enough to become a significant thermal control perturbation. Of the four chambers, three have round walls with three different radii, and one has flat walls. Cylindrical walls cause severe optical problems in achieving good detail resolution and evenness of illumination. The chamber's depths varied from 7. 5 to 20 cm. Particles as small as 5 to 10 μm are to be resolved. This calls for a long working distance microscope with a variable working distance to accommo- date all the chambers. To use one microscope whose working distance fitted only one chamber and consequently have a total of four different micro- scopes was unacceptable. The viewport solutic . adopted is covered in detail later. The overall configuration is shown in Figures 6-18 and 6-19. The fifth chamber is the continuous flow diffusion chamber which is the primary
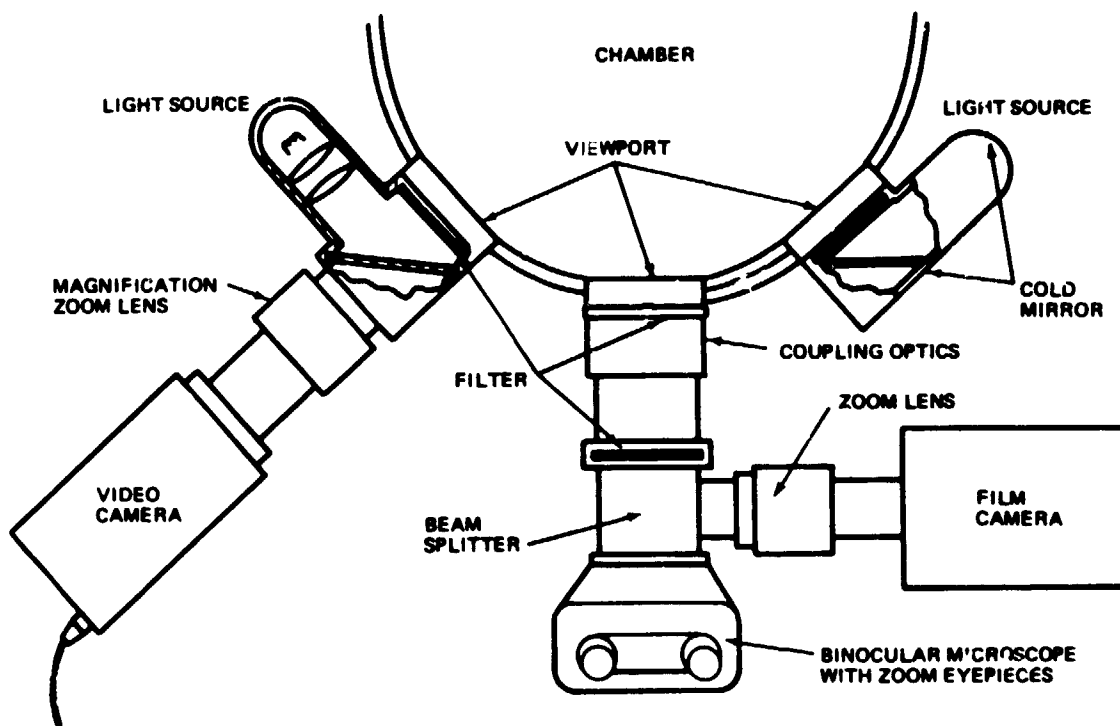
Figure 6-18. Standardized Chamber Optical Configuration
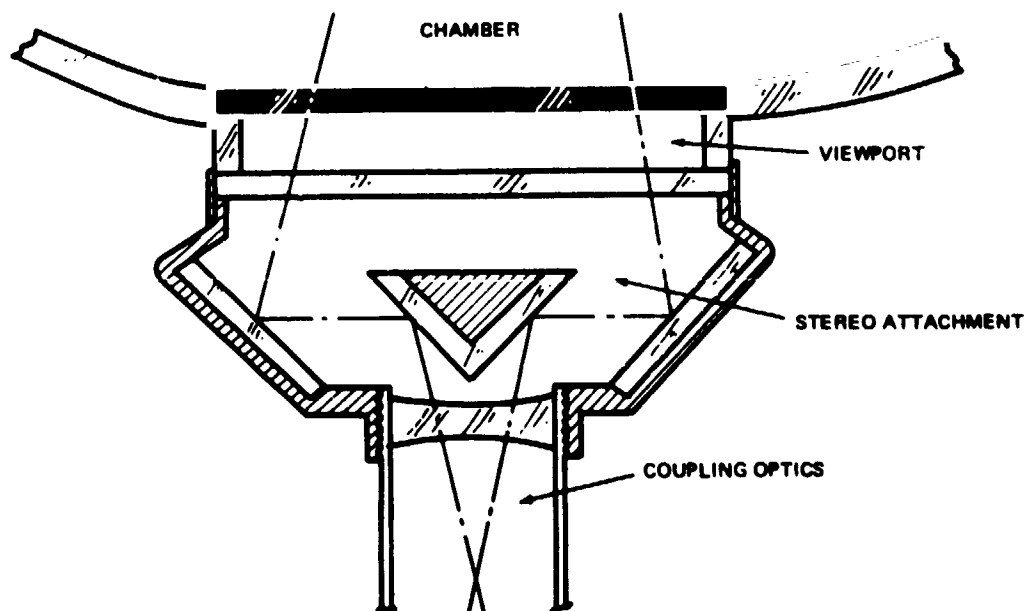
Figure 6-19. Standardized Chamber Optical Configuration

chamber for Experiment Class 1 only. An optical particle size and distribution counter is the only optical observation and recording requirement and therefore does not require optical access.

6.3.4.2 Focal Range

The particles cannot be fixed in the center of the chamber. The experiment conditions within the chamber show that the particles may be at varying distances from an observational viewport. The optics must accommodate a set of scenes with dynamic focus requirements. The following table summarizes these requirements. Near and far focus limits were developed as $\pm 1/4$ the chamber interior depth.

If we allow 5 cm additional to accommodate a viewport thickness, then the distance from a focused particle plane to the vertex of the closest negative lens of the zoom coupling optics will range from 8 to 35 cm. A paraxial lens design was accomplished. It consisted of a positive and a negative lens. The positive element moves for the zoom, changing its separation from the negative element from 3.44 cm to 7.92 cm to meet the focus range of 35 cm to 8 cm (see Figure 6-20), satisfying the chamber focus requirements.

| Chamber | Focus From Chamber Wall | | Chamber Depth |
	Near	Far	
SDI	10 cm	30 cm	40 cm
SDL	3 cm	1? cm	15 cm
CFD	None	None	30 cm
EXP	8 cm	23 cm	30 cm
GEN	8 cm	23 cm	30 cm

CHAMBER
WALL

VIEWPORT

|← 3 CM →|← 5 CM →|← 7.39 CM →|

CHAMBER
INTERIOR

|← 15 →|← 5 →|← 5.0 →|

|← 25 →|← 5 →|← 3.75 →|
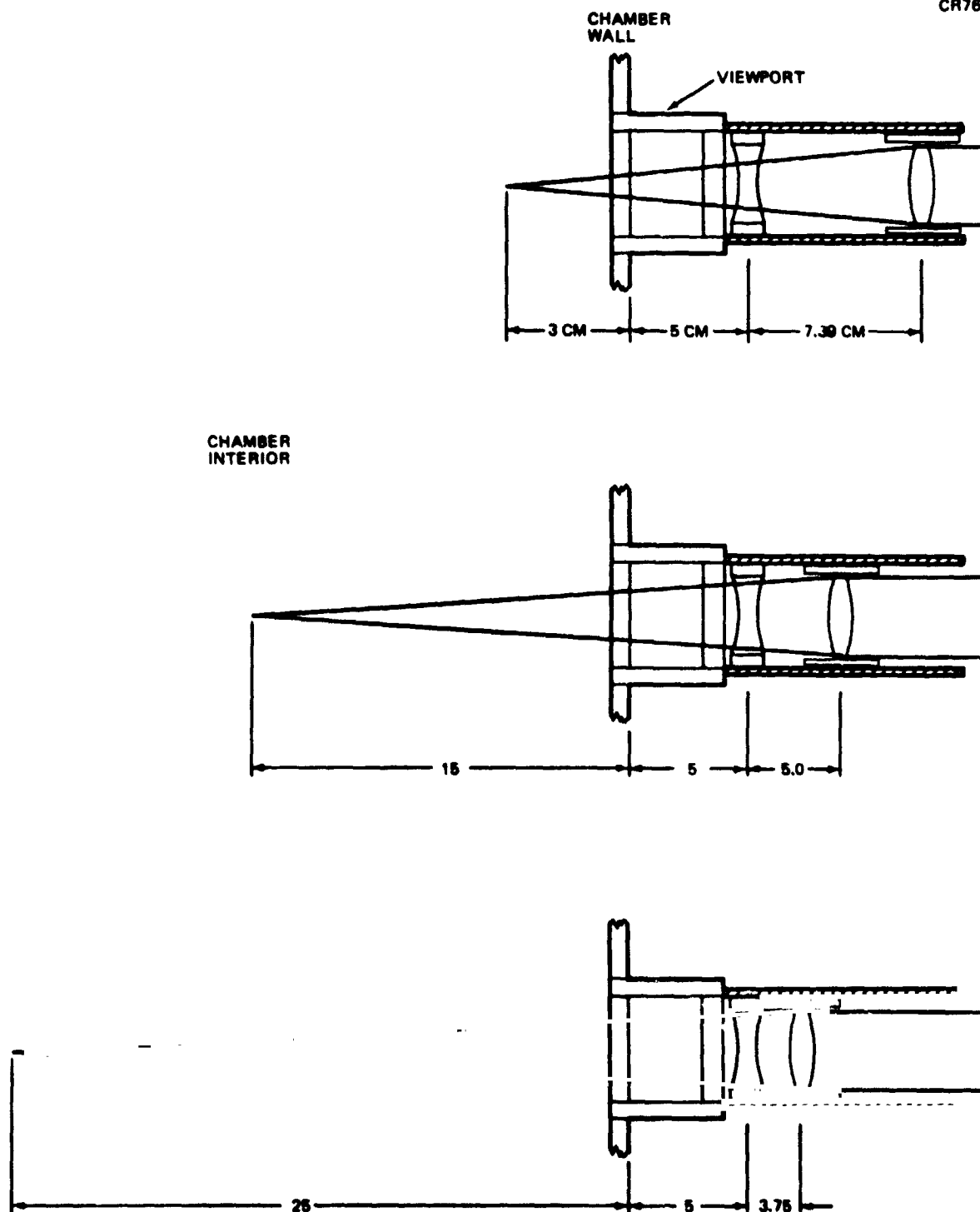
Figure 6-20. Coupling Optics Zoom Focus Capability

6.3.4.3 Lighting

Lighting of the experiment subject must be controlled not only in its intensity but also in its directionality to control bounce light, duration, spectral content (reduce particle heating), perhaps polarization and coherency. Although both lighting and observational functions can be performed through one optical access port by beam splitting, it is undesirable since flare light will increase and mask particle detail. Particles would be front lighted on an illuminated background — providing poor contrast. For a flat transparent walled chamber, the lighting can be introduced from the side walls - crossing in front of the observational optics (Figures 6-21 and 6-22). Depending on the particles, front or side lighting may be appropriate.

Figure 6-21 illustrates the illumination module. A 60 to 100 w tungsten-halogen bulb illumination is collimated and passed into the chamber either
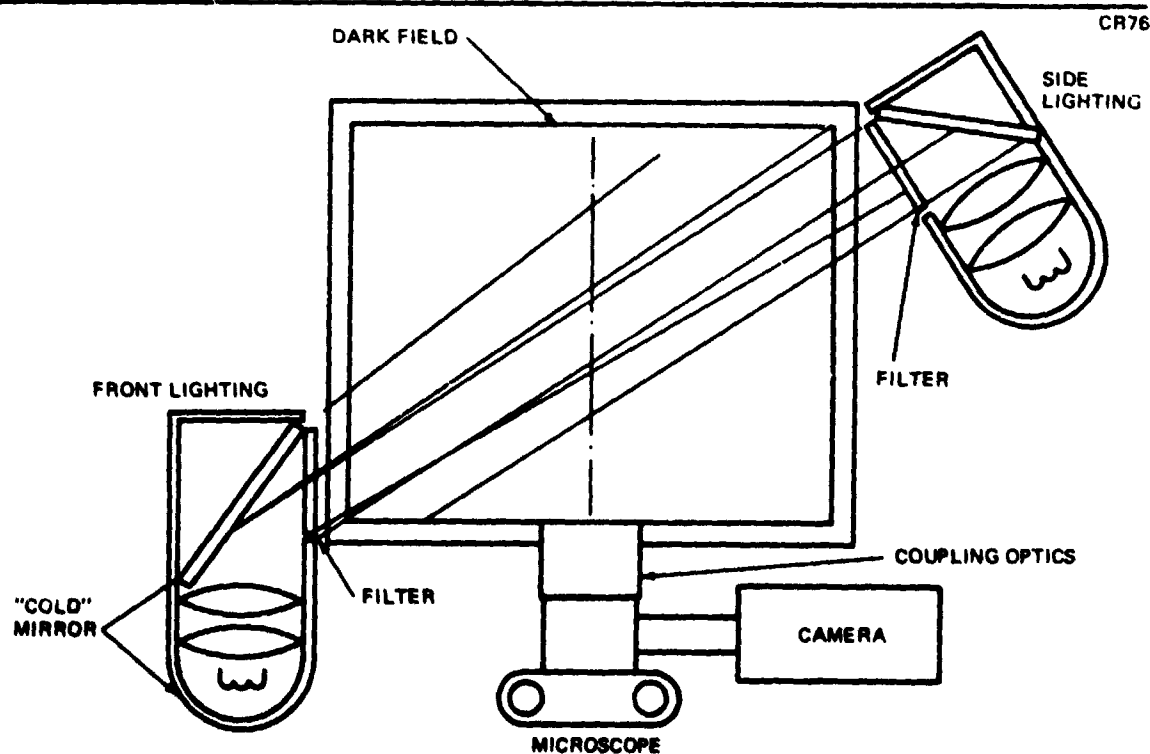
Figure 6-21. Illumination Module
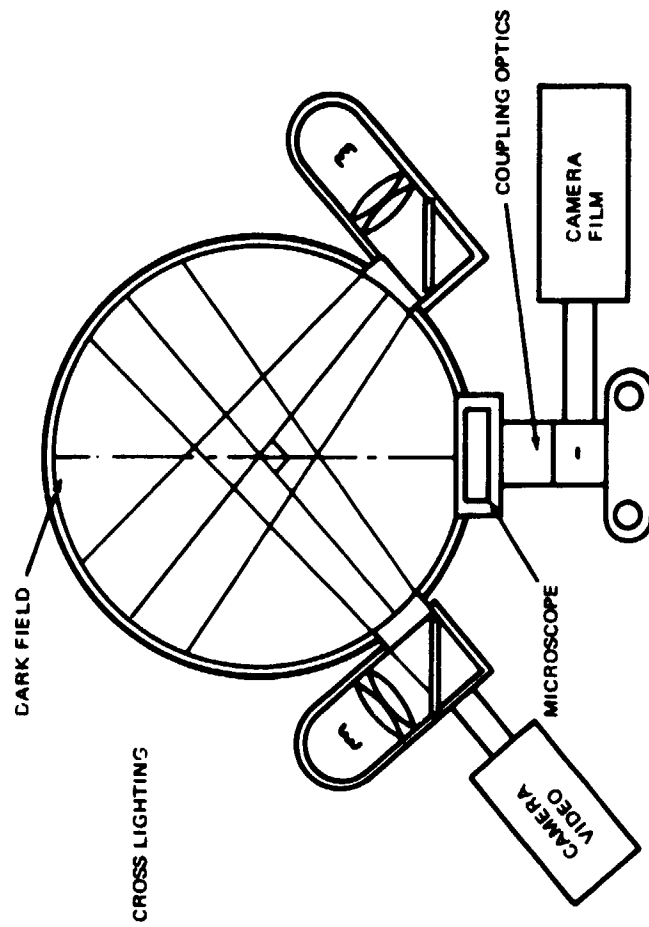
Figure 6-22. Cross Lighting

through flat transparent walls or a flat viewport. The bulb is at the focus of a spherical reflector but just slightly off axis. The reflector forms an image of the rear side of the filament just above the filament. This technique recovers over 50 percent of the lamp illumination which would otherwise be lost. The collimated light is directed by means of a "cold" mirror. Both this flat mirror and the spherical mirror have dichroic coatings. These coatings are reflective up to about 700 to 800 nmi where they begin to transmit the heat producing IR. The bulb and socket will be demountable so that a small xenon short-arc bulb (such as Illumination Industries, Inc., standard model FRT-6) can be inserted for strobed illumination. There is provision for filters so both neutral density and polarizing filters may be inserted if required.

6.3.4.4 Viewports

The cylindrical walled chambers (E, SDI, SDL) have three different wall curvatures: 20, 15, and 7.5 cm. When observing through this equivalent cylindrical lens, the refractive power lies in only one axis while the wall behaves like a flat plate in the perpendicular axis. This refractive power can be compensated if the observed particle lies on a radius that intersects the wall at the point of observation. Images of particles not on this axis are aberrated with the degree of aberration increasing rapidly as the particle position departs farther and farther from the radius to the viewpoint. To observe 5 to 10 μm diameter particles with reasonable fields of view and a focal depth is an impossible requirement. Observing through a flat wall with changing chamber pressures introduces a much less severe class of optical aberrations. These can be compensated in the coupling optics design to achieve the required; resolution, field of view, and focal depth. This problem is identical to microscopic observation through a cover glass. Illumination can now be directed at various angles through the flat walls without affecting the evenness of the level. Much as the window in a house, the viewport can be a thermal leak that disturbs the chamber's thermal control. By making a sealed double walled viewport, this problem is minimized. Optically, no new aberrations are introduced with two flat walls. These are equivalent to one flat wall whose thickness equals the sum of the two walls' thickness. The viewport is assembled from a hollow cylinder of glass and two flat circular pieces of glass which are glass soldered together.

By specification, the flat pieces will be without birefrigent strain, and without homogenity defects which degrade resolution when assembled. Flat walled ports, costwise, are much cheaper and have more utility than using compensating anamorphic optics for the circular chambers.

6. 3. 4. 5 Distortion Calibration

In some of the experiments (classes 4, 10, 17) droplet dynamics trajectories will be filmed and the individual frames photometrically reduced. The optical system will require calibration to recover the tangential and radial distortions. Since the focus will be changing during a filming sequence, the distortion calibration must be made through the expected focal range and magnification range. The method is simple and will be used only when necessary.

6. 3. 4. 6 Data Management Requirements

As the focus on the zoom optics is changed to follow a dynamic particle inter-action, it will be necessary for the onboard computer to monitor and record focal position as the astronaut changes it. This prevents distracting his attention from the experiment's progress to record focus.

There is a general area of data management to support the optical subsystem which can be described functionally. Within the magazine of each camera, a data block will record on each film format enough information so that the event recorded can be traced back to: the particular experiment performed, the time the event occurred, and any other relevant data. The simplest recording is a digital time block. The time line thus established can be correlated on the ground with supporting data recorded by the Data Management and Control Subsystem. Following is a summary of Data Management Requirements.

<u>Optical Subsystem</u>
<u>Data Management Requirements</u>

1. Record positions of focus zoom lens and magnifications zoom lens throughout an experiment's conduct.
2. Provide digital time word for camera data block in camera magazine.

3. Record camera ON and OFF times and number of frames taken.
4. Record film magazine in use for each experiment.
5. Provide digital time word for magnetic tape record (VTR) of video operation.
6. Record output of optical particle counter with time tags.
7. Video Monitor:
   a. Provides astronaut with wide angle view of chamber. Has reticle defining field of view of microscope, or a grid with 1-in. spacings imposed on the field.
   b. Provide checklist for experiment.
      1) Setup
      2) Camera, lens, illumination level and stroke rate, introvalometer setting, filters or polarizer.
      3) Magazine selection
      4) Experiment procedure outline
      5) Takedown and storage
   c. Permits astronaut to review what he has done and how experiment has progressed.
8. Provide video tape recorder of adequate capacity.

6.3.4.7 Optical Subsystems Interactions

There are five optical subsystems used in the chamber experiments. Any combination of the five may be utilized in any experiment recording. The five optical subsystems are:

   1) Astronaut binocular microscope
   2) Film camera
   3) Video camera
   4) Optical particle counter
   5) Illumination subsystem

It is anticipated that the film camera will be high resolution, small field of view recorder and the video camera will be the low resolution, large field of view recorder. The astronaut will use a binocular microscope to view a somewhat larger field than the film camera. This will provide him with a viewfinder. Through his optics he will be able to: focus the cameras, center

their fields of view, anticipate when moving particles are entering the field of view so as to start recording and conserve film footage, and shift the field of view slightly to capture unexpected dynamic particle movements. The video camera, looking through another port to one side, will provide the astronaut with a second perspective on the subject and with a much wider field of view. This position may be beam split to accommodate an illumination subsystem (see Figures 6-18 and 6-19).

The astronaut will be able to maintain critical focus for the film camera with a zoom lens called the coupling optics. This optical system focuses on a specific field depth and sets the object at infinity for the succeeding optics. The astronaut then utilizes the equivalent of a telescope to view the scene. The film camera following a beam splitter can utilize a commercial lens always focused at infinity but with a magnification zoom capability and electronically controlled iris. Since zoom lenses (due to lens design limitations) do not have the resolution capability of a fixed focus lens, a trade study was conducted to determine whether a set of fixed focus lenses of different focal lengths is a better choice than a single zoom lens from the criteria of; required resolution, field of view, operational utility, cost, reliability and maintainability, and required interface controls with the Data Management subsystem.

6.3.4.8 Holography
Some of the experiments involving clouds of particles such as; 8, 9, 12 and 17, require a depth of fields that cannot be obtained with lens type imaging. Holographic recordings can be made of these clouds and magnification, counting, etc. can be performed at a later date.

In the simplest case, all of the experiments (except for submicrometer particle counting) could be recorded holographically. This would remove the very small depth of field limitation of lens type imaging. However, the holographic recording medium must have sufficient resolving power to reconstruct the object wave. The required resolution depends on the object size, type of hologram and the geometrical arrangement. For the in-line

Gabor type hologram, which requires the least resolution, the recording medium's resolution limit directly results in a limitation of image resolution. An off axis Fourier transform holographic image is limited in field coverage for a limitation in recording medium resolution. Since the spatial frequency spectrum of the object wave is the same as that of the object to be recorded, recording the object wave requires no more resolution than it requires to record a direct lens generated image of the object. For off axis holograms, the recording medium should be able to resolve at least twice the highest frequency contained in the object spectrum. This is necessary to prevent overlap between the image and the zero order flare light. To record the full field of view, the recording medium must resolve the spatial frequencies generated by the interference of the light from each object point with the reference beam. This requirement is different for each type of hologram.

Fog hologram cameras have been operated at a recording rate of 30 per minute. The sample volume recorded was 7 cm^3 (1 x 1 x 7 cm) with a system resolution of 6 μm. The laser was a pulsed ruby laser with a pulse duration of 0.5 μ second.

The use of holography is considered an advanced concept. It does permit recording a great depth of field which is needed in a three dimensional volume when particle counting. There are several different optical configurations, one of which can produce a 360-degree hologram. In lieu of holography where a stable cloud exists, the light can be collimated into a thin fan and the cloud illuminated. A photograph is taken and then the fan plane is moved to a new position in the cloud with the camera also advancing the same distance. Another frame is exposed. Thus successive shots are taken of successive layers in the cloud. Holographic techniques will not be considered at this time due to time limitations, the advanced nature of the technique, and the obvious cost increases.

6.3.4.9 Resolution

Visual: Under optimum viewing conditions the normal visual acuity is about 1 minute of arc. This extreme limit results in a strain on the eye. For comfortable and continued observation 3 to 6 minutes of arc are very workable

visual acuities. A very general rule of thumb is to use as much magnification as the largest number of line pairs per millimeter to be observed. Thus to observe 50 lp/mm, use 50X. If the astronaut is to observe 10 μm diameter particles, he will need 100X. The workable object acuity depends upon the contrast with the background and the velocity of movement. To insure that unfavorable viewing conditions can be met, we will use this general rule of thumb for viewing magnification.

Photographic: The lighting of the particles will be arranged so that they are well illuminated with a well collimated source. The background will be kept as dark as possible by controlling the bounce light inside the chambers. This will maximize the contrast of the particles. The collimation of the light and the diminished bounce light level should enhance detail contrast on particles with sizes approaching one millimeter. The greater the image contrast, the greater the resolution capacity of the film. For 1:1 imaging of a 5 μm particle, a resolving power in the lens-film combination must be at least 200 lp/mm. To insure a working resolution of 50-100 lp/mm, a magnification of 4X is required. The zoom coupling optics has a 2:1 zoom capability in order that particles 3 cm to 28 cm from the chamber wall can be held in focus. Thus one coupling optic will suffice for all five chamber sizes. By maintaining a 5 cm entrance pupil diameter, the effective f/no. will be no worse than f/8.6 at normal atmospheric pressure. The diffraction limited resolving power for this f/no. in 550 nm light is 228 lp/mm. This means that two high contrast particles illuminated by 550 nm wavelength incoherent light will just be resolved through this f/8.6 relative aperture if their separation is no smaller than 4.4 μm. Therefore the numerical aperture of the coupling zoom optics on the particle side will always be great enough to resolve a 5 μm particle at a distance of 28 cm from the chamber wall. Smaller particles can be detected provided the light they scatter into the optics is sufficient to active the recording film.

Video: Unlike film whose horizontal and vertical resolution is the same, the video camera vertical resolution is a function of the number of scan lines in the raster while the horizontal resolution is a function of the video bandwidth. Like film, both horizontal and vertical resolution is also a function of the contrast or modulation in the object.

Standard broadcast TV has a video bandwidth of 4 MHz. The video frame has an aspect ratio of 4:3 originally set to conform to the standard motion picture practice. TV resolution usually falls to half the center resolution at the edges of the video frame. Video resolution is usually quoted as the number of black lines distinguishable in a standard TV test chart. For a quoted resolution of N lines (normally alternate black and white lines) the width of each line is 1/N times the picture height. Note that a standard horizontal resolution may be 300 lines as quoted, but due to the 4:3 aspect ratio, the total number of alternate black and white lines that may be resolved horizontally is 4/3 x 300 = 400 lines.

If a photographic tribar resolution target were imaged by a 525 line, 4 MHz, 30 frame/second, 35 mm target, vidicon and it is required that 2 TV lines are required to always resolve one bar or one space in the tribar target, then the video resolution will be 5 line pairs/mm on the target cathode. Compared to a film like Linagraph Shellburst whose high contrast resolution is 125 line pairs per mm on a tribar target, this video resolution is 1/25 as much.

The following table shows TV horizontal and vertical resolution of line pairs per frame on 1 inch tube, 4:3, 30 frames/second.

| | Horizontal | | | | |
Line Rate/Frame	4 MHz	8 MHz	16 MHz	32 MHz	Vertical Center
525	400	650	1200	1400	340
1023	--	325	625	1200	650
1225	--	250	500	1000	775

To enable the vidicon camera to match the resolution of the film camera, the video scene must be magnified about 25X that of the film scene scale. Or if the film camera uses a 50 mm focal length lens, the video camera must use a 1250 mm lens. If this appears more practical to utilize the video camera as a wide field, low resolution recorder, the astronaut can use it for an overall chamber view which his microscope will not be able to do.

The vidicon enjoys two advantages over the film camera. When particles are in motion, the duration of the horizontal scan on a resolution element which is about 50 μsec would be sufficient to stop motion of a just resolved spot. The ordinary vidicon tube is about 50X faster than a fast silver halide film like Kodak Royal X Pan. The silicon diode array camera is 10X as sensitive as the vidicon. The intensified silicon target camera is 10,000X as sensitive as the vidicon. The illumination level is not expected to be a problem. The sensitivity level and light range capability of the vidicon should be adequate for our needs. There is no overriding reason to go to a high resolution camera from a resolution standpoint. The high resolution camera, monitor and camera control unit costs 1.20X the standard system besides being not compatible for real time transmission over the Shuttle's standard video link.

6.3.4.10 Special Optical Requirements

Stereo: Stereoscopic photography permits greater surface detail definition and motion vector sensing than two dimensional recordings can provide. The requirement for stereo can be met in various ways. The viewport can be enlarged horizontally to about twice the dimension needed for monocular viewing and a stereoscopic split field attachment added to the coupling optics. Each 35 mm frame, for example, would record two fields with each field taking up 24.5 x 18 mm of the full 24.5 x 36 mm frame. Alternately, two viewports can accommodate two camera systems, or one special camera body holding two lenses and one strip of film could b used. Considering simplicity, cost, and final results, it is concluded that the enlarged viewport and detachable stereo attachment is the optimum solution.

Color: Some requirements for color recording have been established.

Polarimetry: Using polarized light to illuminate a cloud of ice and water particles is a standard method to discriminate ice from water due to the birefringent nature of the ice crystal. Filter holders are provided in the light source housing and coupling optics mount for the polarizer and analyzer filters. Color recording would give much better definition of a crystalline

structure (Experiment 5, Ice Crystal Growth Habits). However image conversion video systems are available that can convert the grey scale of a black and white recording to a color scale. The eye has far greater color scale discrimination than grey scale discrimination. MDAC has such a system and has considerable experience in its use.

Section 7
TEST PHILOSOPHY AND PLAN AND SAFETY, RELIABILITY AND MAINTAINABILITY ANALYSES

This section is comprised of four separate studies to support the CPL Project: (1) Test Philosophy and Test Plan, (2) Preliminary System Safety Plan, (3) Reliability Analysis, and (4) Maintainability Analysis.

7.1 TEST PHILOSOPHY AND TEST PLAN

The goal of the CPL test philosophy is a well-conceived test plan which will prove technical performance and establish the necessary confidence to provide a versatile, user-oriented CPL that is safe for personnel and maximizes mission success in the most cost-effective manner.

7.1.1 Test Philosophy

The test philosophies associated with previous programs have required testing to expected life at all levels of hardware and to abnormal design environments. The previous programs have had to contend with technological advances not anticipated in the initial planning phases and have had multiple vehicles from which to gather reliability data. These programs have had to contend with no capability for return from orbit for on-ground maintenance and refurbishment. The benefit of sufficient resources for several test units to verify their designs was also a prime test philosophy factor.

The Zero-Gravity Atmospheric Cloud Physics Experiment Laboratory (CPL) has similar objectives for reliability and safety as these previous programs, but can build upon their successes. The nature of the CPL, its maintainable design, its operation in a room-ambient environment in the Spacelab, and the availability of two CPL's for the 40-mission 10-year program all combine to

dictate that the concepts used in planning past test programs can be adjusted toward less ground testing, while meriting equally high confidence in system performance.

A development test program encompasses supporting research and technology results; development and qualification testing of parts, components, sub-assemblies, and assemblies of subsystems; reliability testing of selected items; repairability/maintainability testing of the smaller items; development, qualification, maintenance, and maintainability testing using major or vehicle level test articles; and flight testing of the completed contract end item.

Assurance of reusability of the CPL through equipment life, maintainability, and/or refurbishment begins with design and continues through component and vehicle level testing to mission operations. The foundation of such assurance is the intelligent design of components and subsystems for high inherent reliability and long life. Accordingly, every economically practical means of reducing to a functional minimum the number of failures that might occur must be applied to the design effort.

In terms of reducing total maintenance hours to a minimum, it would be ideal to achieve total elimination of failures. However, even if this were function-ally possible to accomplish, the cost of providing the capability of trouble-free service for the projected life of the CPL and proving it to a high level of confidence would be prohibitive. The inevitable risk of unforeseen oper-ational accidents, the fact that it is not feasible to totally eliminate failures, and shear economics indicate a need for supplementary approaches and techniques such as redundancy and failure-tolerant design. Design for high reliability and judiciously planned and implemented testing will be used to ensure the specified reusability and service life of the CPL.

The most cost effective general approach combines four philosophies pertinent to design, analyses, and test.

    A.   Select existing hardware which is shown to have survived space flight; research the history of that hardware to determine durations of missions flown and the amount of testing accomplished to assure

survival to (or beyond) that duration; introduce redundancy into designs which include that hardware; utilize maintainability ($\underline{M}$) analyses to establish scheduled maintenance ($\overline{M}$) procedures for removal and replacement; and conduct qualification tests at higher levels of assembly, e.g., subsystem, assembly level, for CPL criteria.

B. Design new subsystem hardware to survive an economically reasonable portion of CPL life; conduct development and qualification tests to establish and verify that survivability and, from a maintainability ($\underline{M}$) analysis, schedule removal and refurbishment/replacement accordingly.

C. Determine, through reliability analyses that assembly/component reliability meets CPL requirements and that failures which may occur must be considered random failures, i.e., the probability of a failure occurring on the first flight is as great as the probability of a failure occurring on any subsequent flights; introduce redundance into designs which include that hardware, or accept the risk of a random failure; remove and refurbish/replace as necessary in ground maintenance ($\overline{M}$).

D. Determine that a component/subassembly/assembly/subsystem cannot be removed and replaced through scheduled or unscheduled maintenance; design for survival through CPL environmental criteria beyond expected life; and conduct development and qualification tests to assure survival beyond design requirements

7.1.2 Test Plan

7.1.2.1 General

Efforts during Phases B and C of the CPL project will lead to updated definitions of test philosophy, test requirements, and test plans. In keeping with the foregoing general approach, the following preliminary test requirements are established for the CPL:

A. Qualification testing is required for advanced development type components and assemblies, when failure would result in loss of life or Spacelab module.

B. Qualification testing is not required at the component or assembly levels for state of the art, previously qualified, and fully developed and proven products that have been used successfully o.1 other programs.

C. Verification by certification is required when failure would result in loss of ability to conduct an experiment or meet all experiment objectives.

D. Maximum use of means other than testing will be employed to qualify all other failure modes of new parts: analysis, simulation, inspection, and demonstration.

Development tests are performed to determine and evaluate design feasibility, functional parameters, technical data, packaging and fabrication techniques, and environmental limitations. This category includes tests designed to demonstrate that the design meets the specified requirements, to identify critical areas where design improvement may be required, or to identify primary failure modes or critical environments. In addition, these tests are used to demonstrate that the probability of passing qualification is sufficiently high to warrant commitment of equipment to qualification test. These tests may be conducted at any hardware or software level and include compatibility or integration tests. The qualification tests are performed to demonstrate specification compliance.

Three major test articles will be utilized in the ground test program for subsystem and system integration and system level testing: (1) mockups; (2) the functional model (FM); and (3) the project verification model (PVM). Development of the ground support equipment (GSE) is accomplished in connection with development of the FM and PVM. The planning is to limit the models to a minimum number and yet satisfy the development and operational requirements. An example of this is the utilization of the PVM for multiple purposes discussed below.

Mockups are relatively inexpensive development tools which prove invaluable in early verification of many facets of the design. The installation mockup, which will be updated from Phase B and Phase C activities, will be

maintained to reflect the current design as the design progresses toward the operational phase. The mockup will consist of the complete interior and necessary exterior portions of the CPL and will be used as a development tool for optimizing man-system interface relationships.

The functional model is a development tool that is functionally equivalent to an operational vehicle, but in a rack-and-panel type assembly. The FM can utilize either nonqualified or qualified equipment and components. Development test hardware at the component, assembly, and subsystem levels will be used to the maximum extent possible. In addition, the FM consists of qualifiable-type, prototype, flight equivalent. and simulated aerospace vehicle equipment (AVE). The major objective of the FM is to perform interface development testing among AVE subsystems and between AVE subsystems and GSE in preparation for support of the system-level integration and development testing. The FM will be maintained at the factory as a development tool for interface verification of later requirements for update installation.

The project verification model (PVM) is used for multiple purposes. The initial use of the PVM is to provide a check of the physical compatibility of subsystem design configurations early in their development. Nonoperational subsystems are used for manufacturing development and tool fabrication. The primary objectives are:

    A.   To verify manufacturing methods.

    B.   To check assembly procedures.

    C.   To assist in determining tooling requirements.

    D.   To establish control line and cable routing.

    E.   To establish electrical wire harness routing.

    F.   To verify component accessibility.

    G.   To develop and verify maintenance procedures.

    H.   To facilitate design change feedback.

    I.   To serve as an additional man system procedure definition tool.

    J.   To verify mechanical clearances.

To the maximum extent possible the PVM will utilize qualification test hardware from the component, assembly, and subsystem level tests and which has been refurbished to be equivalent to flight-qualified hardware. Some time prior to completion of tool fabrication, these flight-equivalent subsystems will be utilized in the PVM. From this time forward and prior to GPL launch, the PVM includes people, procedures, facilities, and production equipment and is used to verify development completion of the CPL at the factory and at KSC. At the factory, the PVM will be used for system integration testing, software development and operating procedure development. This model will be produced in the same factory manufacturing and testing facilities where the operational vehicle is produced. Following manufacturing and checkout at the factory, the PVM will be used for integration activities. This model will be used for training, mission planning purposes, development of baseline experiment data, as well as for the installation of experiments and checkout of CPL modifications for update installation. It is planned that the PVM will serve as the unit used for verifying the interface between the CPL and the Spacelab before delivery of the first flight CPL. Once the flight CPL is delivered, the PVM will become the first ECC flight simulator.

Figure 7-1 shows the general schedule relationships of the various test articles, along with the functions of each test article. Figure 7-2 presents the scheduled sequence of events between authorization to proceed (ATP) and first launch. It also shows the schedule relationship between development program functions, such as design and development, and the major test articles used in performing these functions. (The circled numbers on Figures 7-1 and 7-2 are means of cross-referencing from one figure to the other.) These figures serve as a preliminary basis for determining availability, from a schedule standpoint, of subordinate level test articles for higher level testing.

7.1.2.2 Specific

A correlation of test requirements and test models is presented in Figure 7-3. The matrix identifies which test model or unit is used to fulfill each test requirement from component level through system level.

Figure 7-1. Schedule Analysis Model Plan
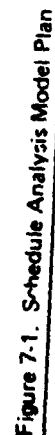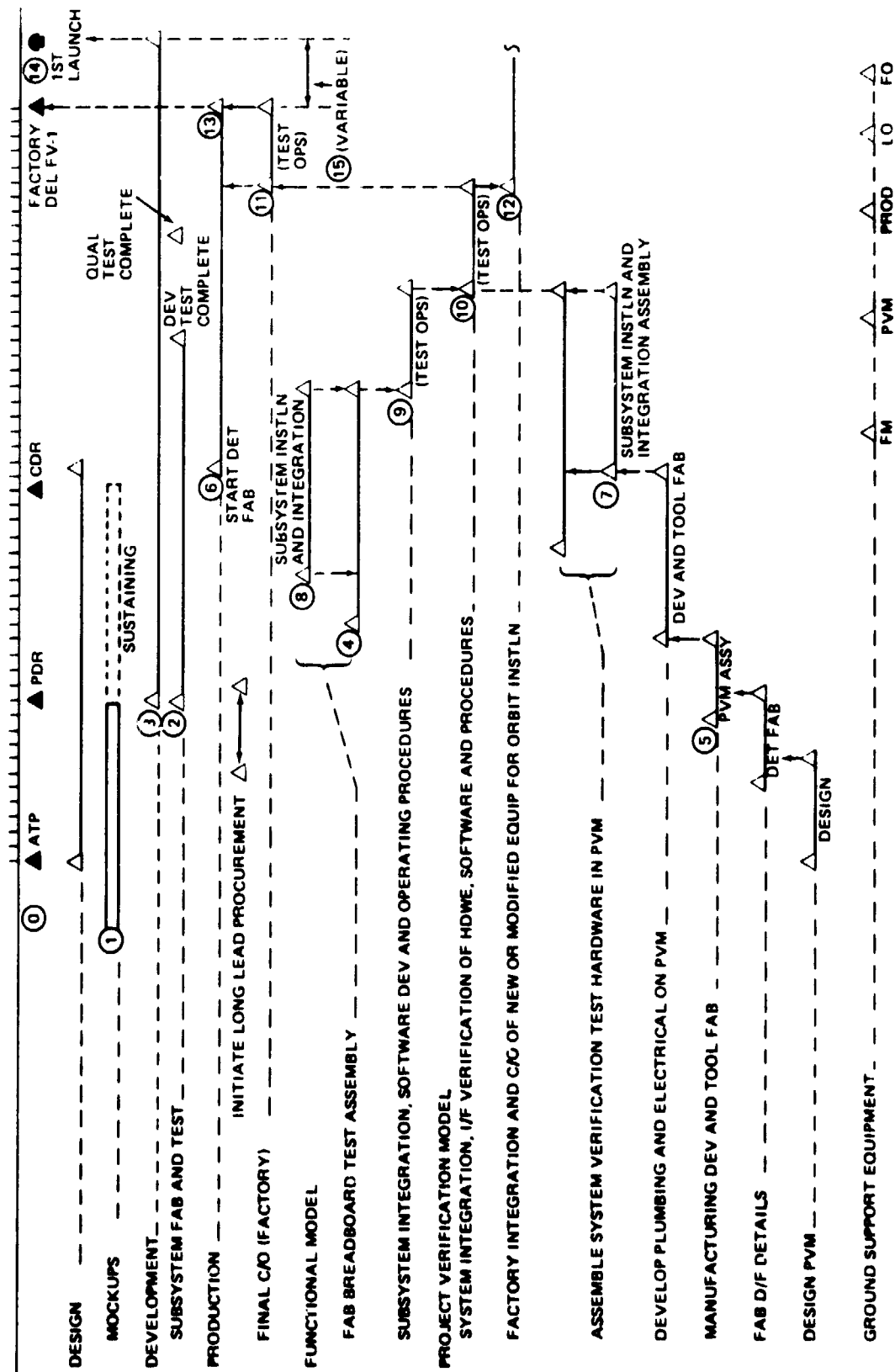
Figure 7.2 Development Program Schedule Analysis Guide

REQUIREMENT	MODEL A DT	B QT	C MU	D SS	E STV	F DYN	G TM	H PVM	J FM	K PTV	L IVU	M SIM	N PROD	O S
COMPONENT/ASSEMBLY DEVELOPMENT	●		●						●			●		
COMPONENT/ASSEMBLY QUALIFICATION		●						●				●		
COMPONENT/ASSEM, INTEG AND SUBSYSTEM DEVELOPMENT									●			●		
SUBSYSTEM INTEG AND SYSTEM DEVELOPMENT								●	●					
SYSTEM VERIFICATION (QUALIFICATION)								●						
SYSTEM ACCEPTANCE TEST								●					●	
STRUCTURE TESTING				●										
THERMAL TESTING				●				●						
MFG DEV AND TOOL FAB								●						
INTERFACE VERIFICATION WITH SPACELAB								●						
GND SYS C/O AND PROC VERIF								●——— OR ——— ●						
PAYLOAD INTEGRATION	———————————————— NOT APPLICABLE ————————————————													
TRAINING, MISSION PLANNING AND SIM								●				●		
OPERATIONAL FLIGHT													●	●
TURNAROUND VERIFICATION													●	●
FLIGHT TESTING													●	●
LAUNCH BACK UP													●	●
ENG DESIGN SUPPORT	●	●	●	●				●	●			●		
PROPULSION TESTING	———————————————— NOT APPLICABLE ————————————————													
EXPERIMENT INTEG (PI)								●				●		

DT — DEVELOPMENT TEST
QT — QUALIFICATION TEST
MU — MOCKUP
SS — SUBSYSTEM MODELS (I.E., BENCH MODELS)
STV — STRUCTURE TEST VEHICLE
DYN — DYNAMICS TEST UNIT
TM — THERMAL MODEL

PVM — PROJECT VERIFICATION MODEL
FM — FUNCTIONAL MODEL
PTV — PROPULSION TEST VEHICLE
IVU — INTERFACE VERIFICATION UNIT
SIM — SIMULATOR
PROD — PRODUCTION (FLIGHT ARTICLE)
S — SPARES SUPPORT OR TESTING

Figure 7-3. Requirement/Model Matrix

Test and test hardware (equivalent units) requirements were determined
at each level: Component, Level 7; Assembly, Level 6; Subsystem, Level 5;
and System, Level 4. These requirements, based on the test philosophy
delineated above and the subsystems technology assessment, were inputs to
various tasks/subtasks of this study.

7.1.2.3 Source and Receiving Inspections and Tests

The objective of the planning for control of one-of-a-kind hardware procured
from subcontractors and suppliers was to receive and use such hardware with
little if any additional inspection or testing. Close coordination and on-the-
spot participation by cognizant contractor and subcontractor technical and
quality assurance personnel will be used to minimize documentation require-
ments and downstream assurance operations. Redundant inspections and
acceptance tests of procured items by the contractor will be avoided. New
quality requirements will not be imposed on suppliers of off-the-shelf items,
or on suppliers of items used on other programs where quality requirements
are at least as stringent as they are for the CPL. Documentation and
reporting requirements for subcontractors and suppliers will be minimized,
consistent with the requirements imposed on the contractor.

It is expected that this test philosophy and test plan may be updated as
additional detailed data are generated during the course of this project.

7.2 SYSTEM SAFETY PLAN

The purposes of this section are fourfold:

A. To present the Preliminary System Safety Program Plan.

B. To provide the Hazard Review Checklist used in evaluating elements
    at the system, subsystem, assembly and component levels.

C. To report the Preliminary Hazard Analysis for the zero-gravity
    CPL assemblies and components.

D. To suggest a Preliminary System Safety Plan for the Phase B
    CPL effort.

It is expected that the Preliminary System Safety Plan and the Preliminary
Hazard Analysis will be updated as additional definition data are generated
during this project.

System safety is a prime consideration in CPL design, production, and operations to minimize the potential hazards to ground and flight crews of the Shuttle/Spacelab and to assure compatibility with their safety interface criteria. Safety evaluations are closely coordinated with reliability and maintainability evaluations to assure satisfactory risk control approaches. The laboratory configuration has been assessed to identify significant potential safety hazards. Related safety provisions and approaches have been reviewed, where data are available, for man-rated programs such as the Skylab, Saturn, Shuttle, Spacelab, and the Tug to better apply past experience and to assure compatibility. General system safety criteria and decision approaches have been developed to be applied in subsequent design and operations phases and in an updated System Safety Plan to be formulated in the subsequent program phase.

7.2.1 System Safety Program Plan

1.0 Scope and Objective

1.1 Scope

This plan defines the activities conducted by MDAC in implementing a System Safety Program for the Zero Gravity Atmospheric Cloud Physics Experiment Laboratory (CPL).

1.2 Objective

The objective of this plan is to outline the methods to be utilized in developing safety design characteristics.

2.0 Definitions

2.1 Hazard Classification

Identified hazards are evaluated and classified as follows:

2.1.1 Safety Catastrophic. Condition(s) such that environment personnel error, design characteristics, procedural deficiencies, or subsystem malfunction will cause system or personnel loss.

2.1.2 Safety Critical. Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem malfunction can be counteracted by urgent crew action (no time available for ground/flight crew analysis) to prevent system or personnel loss.

2.1.3 Safety Marginal. Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystems malfunction can be counteracted or controlled with time available for ground/flight crew analysis to prevent system and/or personnel loss.

2.1.4 Safety Negligible. Condition(s) such that personnel error, design characteristics, procedural deficiencies, or subsystem failure will not result in system or personnel loss.

2.2 Hazard Reduction Precedence Sequence

To eliminate or control hazards, the following sequence or combination of items shall be used as a minimum:

2.2.1 Design for Minimum Hazard. The major goal throughout the design phase shall be to ensure inherent safety through the selection of appropriate design features as fail safe/ fail safe combinations and appropriate safety factors. Hazards shall be eliminated by design where possible. Damage control, containment and isolation of potential hazards shall be included in design considerations.

2.2.2 Safety Devices. Known hazards which cannot be eliminated through design selection shall be reduced to an acceptable level through the use of appropriate safety devices as part of the system, subsystem, or equipment.

2.2.3 Warning Devices. Where it is not possible to preclude the existence or occurrence of a known hazard, devices shall be employed for the timely detection of the condition and the generation of an adequate warning signal. Warning signals and their application shall be designed to minimize the probability of wrong signals or of improper personnel reaction to the signal.

2.2.4 Special Procedures. Where it is not possible to reduce the magnitude of an existing or potential hazard through design, or the use of safety and warning devices, special procedures shall be developed to counter hazardous conditions for enhancement of ground and flight crew safety. Precautionary notations shall be standardized.

3.0 System Safety Tasks

3.1 Safety Analysis

The identification of hazards is accomplished by applying the safety criteria to the system concepts/design and to the operation concepts/plans.

The application of the safety criteria results in the cause and effect displayed as a hazard analysis. The hazard analysis is guided by the undesired event, energy source, system/subsystem function/event, and the operational flow of the system.

As the hazards are identified, the proposed solutions are reevaluated against the system and operations to assure that the impact of the solution will not provide an undesired effect upon the system.

The technique applied is the Preliminary Hazard Analysis. This analysis is performed to show gross hazards in all program events for equipment and operations. The purpose of this analysis is to develop a complete understanding of the system and identify areas where control of the hazard can be accomplished by prudent design or functional controls. The process is iterative in nature and results in improved system design.

3.1.1 Preliminary Hazard Analysis (PHA). A PHA has been conducted as the initial system safety analysis task. This analysis has been a general qualitative study of the subsystem in its operating environment to detect and define potential hazards. This analysis has identified features which can impair mission capability through accidental damage or loss and aid in developing steps which can be taken to ensure that these features are avoided.

3.1.2 Hazards Analysis Action. All analyses developed are coordinated with the appropriate design or operations group for their concurrence. The information developed has been utilized to control the hazards identified through application to the design by the responsible engineering group. If adequate resolution cannot be accomplished at the designer level, the hazard data is submitted to the management level for resolution.

7.2.2 Hazard Review Checklist

A typical Hazard Review Checklist is shown in Table 7-1 and shows the various factors (listed alphabetically) that must be considered in the design of the system to minimize potential hazards.

Table 7-1

HAZARD REVIEW CHECKLIST

1.	Acceleration	12.	Pressure
2.	Contamination	13.	Radiation
3.	Corrosion	14.	Replacement, chemical
4.	Dissociation, chemical	15.	Shock
5.	Electrical	16.	Stress Concentrations
6.	Explosion	17.	Stress Reversals
7.	Fire	1o.	Structural Damage or Failure
8.	Heat and Temperature		
9.	Leakage	19.	Toxicity
10.	Moisture	20.	Vibration and Noise
11.	Oxidation	21.	Weather and Environment

The CPL elements at the assembly and component levels have been evaluated using this checklist. The results of this preliminary evaluation are presented in the next subsection.

7.2.3 Hazard Analysis

An analysis has been conducted at the assembly and component levels to identify potential safety hazards. This analysis has been based largely on . unctional Operation and Subsystem Definitions, in conjunction with the System Safety Program Plan and the Hazard Review Checklist as outlined above.

The results of this analysis are summarized in Table 7-2. Even though selections have not been made from among the candidate assemblies and components, the conclusions are: (1) none are in the safety-catastrophic classification; (2) a few are in the safety-critical classification; (3) most are in the safety-marginal or safety-negligible classifications; and (4) these hazards can be reduced by applying one or more of the methods described in the above System Safety Program Plan, Hazard Reduction Precedence Sequence. Following are the definitions of the column headings in Table 7-2.

Table 7-2 (Page 1 of 5)
HAZARD ANALYSIS

Hazardous Material/Operation/ Condition	Possible Incident	Worst Probable Consequence	Hazard Category	Method of Hazard Reduction
Pressurized Tanks	Leak	1) Release of toxic material which, if in sufficient quantity, might cause personnel injury.	Safety marginal	1) Design for minimum hazard - i.e., limit quantity of toxic material.
	Tank rupture - High-pressure	1) Shrapnel from tank penetrates Spacelab shell causing explosive decompression.	Safety critical	1) Design for minimum hazard - i.e., use burst discs to relieve pressure prior to rupture.
	Tank rupture - Low-pressure	1) Bursting of pressurized vessels-localized fragmentation without injury to personnel.	Safety marginal	1) Design for minimum hazard - i.e., use pressure relief valves and/or burst disks to relieve pressure prior to rupture.
Wiring insulation	Fire/explosion	1) Production of toxic gases and smoke. 2) Destruction of material resources. 3) Contamination	Safety critical	1) Design for minimum hazard - i.e., use material which is nonflammable, non-toxic, nonoutgassing and space qualified.
	Outgassing	1) Release of toxic material which, if in sufficient quantity, might cause personnel injury.	Safety marginal	

Table 7-2 (Page 2 of 5)
HAZARD ANALYSIS

Hazardous Material/Operation/Condition	Possible Incident	Worst Probable Consequence	Hazard Category	Method of Hazard Reduction
Thermal insulation	Fire/explosion	1) Production of toxic gases and smoke. 2) Destruction of material and resources. 3) Contamination.	Safety critical	1) Design for minimum hazard - i.e., use special foam insulation which is non-flammable, nontoxic. nonoutgassing, and space qualified.
	Outgassing	1) Production of toxic gases which, if in sufficient quantity, might cause personnel injury.	Safety marginal	1) Design for minimum hazard - i.e., use special foam insulation as noted above.
Water tank	Leak	1) Excessive humidity	Safety negligible	1) Design for minimum hazard - i.e., limit tank volume. 2) Spacelab EC/LS will remove excess humidity
	Tank rupture - Low pressure	1) Bursting of pressurized vessels-localized fragmentation without injury to personnel.	Safety marginal	1) Design for minimum hazard - i.e., use pressure relief valves and/or burst disks to relieve pressure prior to rupture.

Table 7-2 (Page 3 of 5)

HAZARD ANALYSIS

Hazardous Material/Operation/ Condition	Possible Incident	Worst Probable Consequence	Hazard Category	Method of Hazard Reduction
Heaters	Loss of control - excessive heat	1) Overheat Spacelab module	Safety negligible	1) Design for minimum hazard - Spacelab EC/LS will remove excess heat
Charged capacitor	EMI/RFI field generation	1) Interference with Spacelab-Orbiter communications	Safety negligible	1) Millisecond discharges would have minimal, if observable, impact on communications.
Acoustical field generation	Excessive level generated	1) Personnel discomfort	Safety negligible	1) Design for minimum hazard - i.e., include acoustical insulation as noted above.
Laser devices	Impingement on eyes	1) Personnel injury	Safety critical	1) Operating procedure requires use of appropriate eye-protection glasses.

Table 7-2 (Page 4 of 5)
HAZARD ANALYSIS

Hazardous Material/Operation/ Condition	Possible Incident	Worst Probable Consequence	Hazard Category	Method of Hazard Reduction
Lighting	Breaking lamp or tube	1) Contamination of Spacelab module with gas and glass	Safety negligible	1) Design for minimum hazard - i.e., (1) shield against broken glass hazard; (2) fill lamp/tube with nontoxic gas and rely on Spacelab EC/LS to exhaust any released gas.
TV camera	Rupture of tube	1) Contamination of Spacelab module with gas and glass	Safety negligible	1) Design for minimum hazard - i.e., employ space-qualified TV camera having cathode which has withstood launch and recovery environments.
Oscilloscope	Rupture of tube	1) Contamination of Spacelab module with gas and glass	Safety negligible	1) Design for minimum hazard - i.e., employ space-qualified oscilloscope, if available, or qualify to launch, in-flight and recovery requirements.

Table 7-2 (Page 5 of 5)

HAZARD ANALYSIS

Hazardous Material/Operation/ Condition	Possible Incident	Worst Probable Consequence	Hazard Category	Method of Hazard Reduction
Radioactive material	Not properly contained - exposed to Spacelab	1) Personnel injury	Safety critical	1) Design for minimum hazard - i.e., (1) assure proper shielding and structural protection; (2) assure proper operating and maintenance procedure. Note: The radioactive beta source being considered is so small that, if exposed within Spacelab environment, it conservatively would represent a hazard no worse than safety negligible.

Hazardous Material/Operation/Condition — This column carries information as to whether the material is toxic, radioactive, corrosive, etc.; whether the operation may cause a hazardous condition to exist; or whether the conditions of pressure, temperature, voltages, etc., are present.

Possible Incident — This column identifies the incident which is associated with the related hazardous condition.

Worst Probable Consequence — This column provides an estimate of the consequences to the system caused by the incident.

Hazard Category — This column identifies the level of the hazard as defined above in the Safety Program Plan.

Method of Hazard Reduction — This column identifies the method(s) most likely to be applied to reduce the hazards to be within acceptable limits.

7.2.4 System Safety Plan for Phase B

1.0 Safety

The primary goals of the safety program are the assurance (1) that the CPL can be safely produced, and (2) that the delivered CPL is safe, both by itself and in conjunction with other operational elements of the Space Shuttle system. To accomplish this, the safety program includes activities in design, development, test, manufacturing, and operations.

System safety engineering efforts during design and development will be directed primarily toward: (1) hazard analyses; (2) residual hazard reporting; and (3) hazard corrective action.

During manufacturing, test and operations safety will be achieved through four features of the safety program. These are:

- Review of safety significant operations
- Assignment of safety monitors at each major manufacturing operation

- Audit of safety by employe safety personnel on a continuing basis

- Periodic consideration of each operation and accompanying hazards by an Engineering/Employe Safety Committee.

1.1 System Safety

Safety requirements and considerations will be a contributing factor to the selection of design, test locations, and manufacturing operations. Studies will continue to be made as required to verify minimum hazard exposure and acceptability of design and production characteristics with regard to safety.

1.2 Safety Criteria

Safety criteria will be developed where required to provide guidelines and constraints applicable to the CPL system. Safety data, based on MSC 00134 Space Flight Hazards Catalog and S-IVB/Skylab safety studies will be incorporated in vehicle and GSE requirements. Safety requirements will also be incorporated in vendor and subcontractor work packages.

1.3 Hazard Analysis

Hazard analysis is the keystone of the safety program. Hazard analyses will be updated and refined by design feedback, design review data, test planning information, potentially hazard operations review, operational planning information, and safety analysis of operations data from field sites. Additional sources of updating information are the Failure Mode and Effect Analysis (FMEA), and failure reports generated by Quality Assurance. Residual risk will be reported to NASA.

Hazard analyses will be used in the design and development process as a criterion against which the safety characteristics of the system or operation can be evaluated and as a checklist to assure that proper corrective action has been taken.

1.4 Preliminary Hazard Analysis

During this part of the hazard analysis, potential hazard areas
will be identified by criteria including energy sources, suscepti-
bility to environmental influence, fire and explosion potential, and
toxicity.

1.5 System Hazard Analysis

The system hazard analysis will identify hazardous events in the
system such as fire or vent/relief failure and will evaluate these
in the light of effect on the system considering causative mech-
anisms and protective measures available which eliminate the
hazard, reduce exposure, or minimize the probability of
occurrence.

1.6 Hazard Corrective Action

The hazard corrective action system will be maintained by System
Safety Engineering. The main feature of this system will be
corrective action at the lowest feasible functional level by direct
interface between safety and the responsible functional
organization. For more complex hazards, and those where
resolution cannot be obtained, successively higher management
levels will be brought in until solution is obtained.

Hazards identified will be considered closed only when eliminated
or reduced to an acceptable level as evidenced by NASA concurrence
of a residual hazard report. Closures will be confirmed by suc-
cessful test or analysis, as required.

1.7 Test/Operation Safety

Operations in the areas of manufacturing, test, checkout, handling,
and transportation will be selected by system safety and evaluated
by a Safety Significant Operations (SSO) review to assure minimum
probability of CPL or facility damage or personnel injury.

The SSO review will identify, evaluate, and recommend corrective actions for hazards based upon safety and reliability analyses resulting from: (1) the design effort; (2) OSHA and NASA criteria; (3) quality assurance, facility and manufacturing requirements; and (4) functional analyses of the operations.

1.8 Contamination Assessment

Analysis of potential contamination sources from the CPL will be made. Contamination sources will include equipment capable of producing effluents or environments deleterious to crew safety, laboratory experiments, the Spacelab, or other payloads. Typical contaminants include sample gas leakage, light, noise, heat, and radio frequency interference (RFI). This assessment will be used to support formulation of a subsystem contamination specification. Wherever possible subsystem design features will be identified to eliminate or minimize contamination sources.

1.9 Material Control Program

A material control program and the institution of criteria for materials acceptability will be included in the design requirements specifications for the experiment laboratory and ancillary sub-systems. A material control program, developed by MDAC and used extensively in manned simulator tests and in the Skylab program, provides a comprehensive computerized up-to-date list of materials which includes data from NASA, Air Force, and MDAC. The materials listed have been screened for flammability and out-gassing and are grouped according to usage. The MDAC Materials Information Desk also has a computerized listing of the screening tests and acceptance criteria for each category, including combustion rate, CO outgassing, total organics (as CH_4), electrical wiring, and electrical overload. The MDAC materials control program also includes provisions for additional testing of materials used in the construction of the experiment laboratory and ancillary subsystems, for the identification of individual outgassing products whenever such data are not available in the data bank.

7.3 RELIABILITY ANALYSIS

The reliability recommendations are based on cost-per-flight values. This analysis summarizes the impact of various reliability levels in terms of total program costs. These impact calculations reveal that the baseline MIL-STD equivalent reliability level would provide:

A. The lowest relative acquisition cost (DDT&E plus production).

B. The lowest relative total program cost.

C. Increased relative costs for flight and ground operations, and for Spacelab and Shuttle allocations.

The calculations confirm the selection of the MIL-STD equivalent reliability level as the baseline for the Zero Gravity Atmospheric Cloud Physics Experiment Laboratory, based both on total program cost and on cost per flight.

7.3.1 Purpose

The purpose of the reliability analysis is to provide guidance and recommendations concerning reliability provisions to personnel making CPL program, design, and equipment definition decisions.

7.3.2 Objectives

A. Estimate reasonable ranges of CPL reliability for minimum program costs including maintainability range considerations.

B. Define ranges of CPL reliability for reasonable goals, make preliminary allocations to subsystems, and define elements to be included in subsystem and equipment allocations when equipment definition is more specific.

C. Define potential significant reliability problem areas and guidance to attack or avoid such problems.

7.3.3 Approach and Assumptions

7.3.3.1 Reliability — Cost Evaluation and Goals

The following summarizes the approach used in estimating reliability and goals in relation to costs.

Initial Q (Unreliability) Estimate

An initial estimate was made from early available system definition of CPL mission unreliability (Q) based on subsystem/equipment failure rate estimates. An average effective mission operating time including stress factors (30 hours effective) assuming an average mission CPL use time of 40 hours was estimated. Assume a program on the order of a MIL-STD-program for the base estimate from which the subsequent parametric variations was made. (The initial or base Q was estimated as 0.024. Refer to Table 7-3 under the MIL-STD, NOM, nominal column.) Redundancy as a maximum of on the order of 20 percent of the total equipment failure rate for sensing and control of possible safety hazards and for potentially practical mission-success improvements was assumed.

Reliability Level — Acquisition Cost "Z" Factor

A relatively simple relationship yielding the generally accepted reliability-cost trend that acquisition costs increase at a monotonically increasing rate as the Q approaches zero was defined (see Figure 7-4). This Z factor relationship was used in the subsequent evaluations to estimate the CPL acquisition (DDT&E plus production) cost impact of reliability program level changes.

Reliability Level — Q-Program Cost Relationships

A mathematical relationship was developed for total average CPL program costs per mission variable with reliability level as a function of the "Z" program equivalent reliability level and base Q estimate variations. From this a relationship was developed for a minimum program cost "Z" reliability level as a function of Q estimate variations (Subsection 7.3.6). The QSTD or nominal base CPL unreliability estimate was used as the starting point for variations. Program costs that are judged not to vary significantly with CPL reliability level were not included in the relationship since such have negligible impact on the indicated minimum cost points. For example, in-flight maintenance action and cost variations with Q changes were assumed negligible for this evaluation. The average costs estimated per mission were those variable above some essentially constant base. Spacelab (S/L) and Shuttle reliabilities were assumed as 1.0.

Table 7-3

CPL MISSION COST ESTIMATE FOR COSTS VARIABLE WITH RELIABILITY LEVEL

Reliability Level, Z Factor Q, K Level (Reference, Range)	Good Commercial Z = 2			MIL-STD, Z = 1				ER-TX Rel, Z = 1/2				HI-Rel, Z = 1/5			
	High	Nom	L	High	Mod	Nom	Low	High	Mod	Nom	Low	High	Mod	Nom	Low
$Q_{STD} = K_{STD} \cdot (1/Z_{STD})$	0.24	0.024	0.0024	0.24	0.04	(Base)	0.0024	0.24	0.04	0.024	0.0024	0.24	0.08	0.024	0.0024
$Q_i = ZQ_{STD}$ (R_i = Expect Failures)	0.480 48	0.048	0.0048	0.240 24	0.08	0.024	0.0024	0.12	0.04	0.012	0.0012	0.048	0.016	0.0048	0.0005
Q_i/Q_{Nom} (Estimate Variation)	10	1	0.1	10	1	1	0.1	10	1	1	0.1	10	1	1	0.1

$$C_T = \frac{C_{STD}}{7\,AD} \cdot ZQ_{STD}\,C_0 \cdot 8ZR_{STD}\,C_H \cdot ZQ_{STD}$$

C_A = CPL Program Cost Per Average Mission Estimate of Costs Variable with Reliability Level

$C_A = \frac{C_{STD}}{7\,AD} + \frac{\text{Production Cost Per Mission}}{}$

$C_V = \frac{\text{Flight & Ground OPS Cost Per Mission}}{}$

C_L = Repair Cost Missions Period (# Months)

C_{SM} = S/L and Shuttle Allocated Costs Per Mission Lost due to CPL Failure

For Annual Estimate

GOOD COMMERCIAL LEVEL, Z = 2
(EQUIVALENT RELIABILITY PROGRAM LEVEL)

ER-TX EQUIVALENT, Z = 1/2

MIL-STD EQUIVALENT LEVEL, Z = 1

HI-REL, Z = 1/5

RELATIVE COST Ci/CSTD

Z = RELATIVE UNRELIABILITY = Qi/QSTD

EQUIVALENT SYSTEM RELIABILITY LEVEL (PARTS, SYSTEM DESIGN, ANALYSIS, EMPHASIS, CONTROLS, PROCEDURES)	GOOD COMMERCIAL	MIL-STD	ER-TX REL	HI-REL
Z, ESTIMATE OF RELATIVE Q (OR λt = X) TO DEFINE GROSS RELATIVE TRENDS Z = Qi/QSTD, Qi = Z (QSTD)	2	1	1/2	1/5
ESTIMATE OF RELATIVE COST (ACQUISITION, DDT&E + PRODUCTION PROGRAM) TO DEFINE GROSS RELATIVE TRENDS. 1/Z = Ci/CSTD; Ci = CSTD/Z	1/2	1	2	5

CSTD/Ci = Z = Qi/QSTD

SO, Ci Qi = (CSTD)(QSTD) = CONSTANT, IS THE ESTIMATOR USED TO DEFINE THE GENERAL RELATIONSHIP OF SYSTEM ACQUISITION COST WITH UNRELIABILITY (1-RELIABILITY). FOR EXAMPLE, 1/5 THE UNRELIABILITY WILL COST ON THE ORDER OF FIVE TIMES AS MUCH

NOTE: ER-TX = ESTABLISHED RELIABILITY LEVEL, EXTRA TESTING MAY BE REQUIRED.

Figure 7-4. Z Estimator Used to Relate System Acquisition Cost Trends to Program Equivalent Reliability Levels

Initial Cost Estimates

Program cost estimates based on previous CPL studies were obtained from the MDAC-CPL cost and schedule activity. Such costs related to a program were assumed that are equivalent basically to a MIL-STD program in areas such as design and reliability analyses, parts quality, testing, controls, reliability emphasis, and program provisions.

Minimum Cost "Z" Level

Exercise the minimum cost "Z" factor model through a range of Q estimates to indicate least program cost reliability levels and perform a comparison with the program cost model results (see Figure 7-5).

Exercise Q Program Cost Relationship

The program cost model was exercised through various ranges of parameters to illustrate minimum CPL program costs as a function of equivalent reliability program level, of a range of Q estimate potential error, and Spacelab and Shuttle allocated flight costs.

- A. Equation 4 (Subsection 7.3.6) was exercised through ranges of parameters and tabulated in Table 7-3. The starting point was the nominal (nom) Q estimate under the MIL-STD program column and its CA acquisition cost estimate. The acquisition costs vary by reliability "Z" level but were assumed constant within each equivalent reliability level regardless of the reliability estimate variation considered within that reliability level. The "Z" or reliability level factors were applied from Figure 7-4.

- B. Figure 7-6 was developed to illustrate the CPL-only costs for a range of Q, plotting the Q_i nom (nominal) estimate for each reliability level from Table 7-3 as the abscissa and including the effects of an error potential in the Q_i nom estimate on combined CPL-only costs. Repair cost estimates were varied through a substantial range by varying mean-man-hour-per-repair estimates.

- C. Figure 7-7 was developed to compare CPL-only costs and Spacelab plus Shuttle allocated costs lost due to CPL failure as a function of reliability level (Q_i nominal as abscissa) and a range of Q estimate
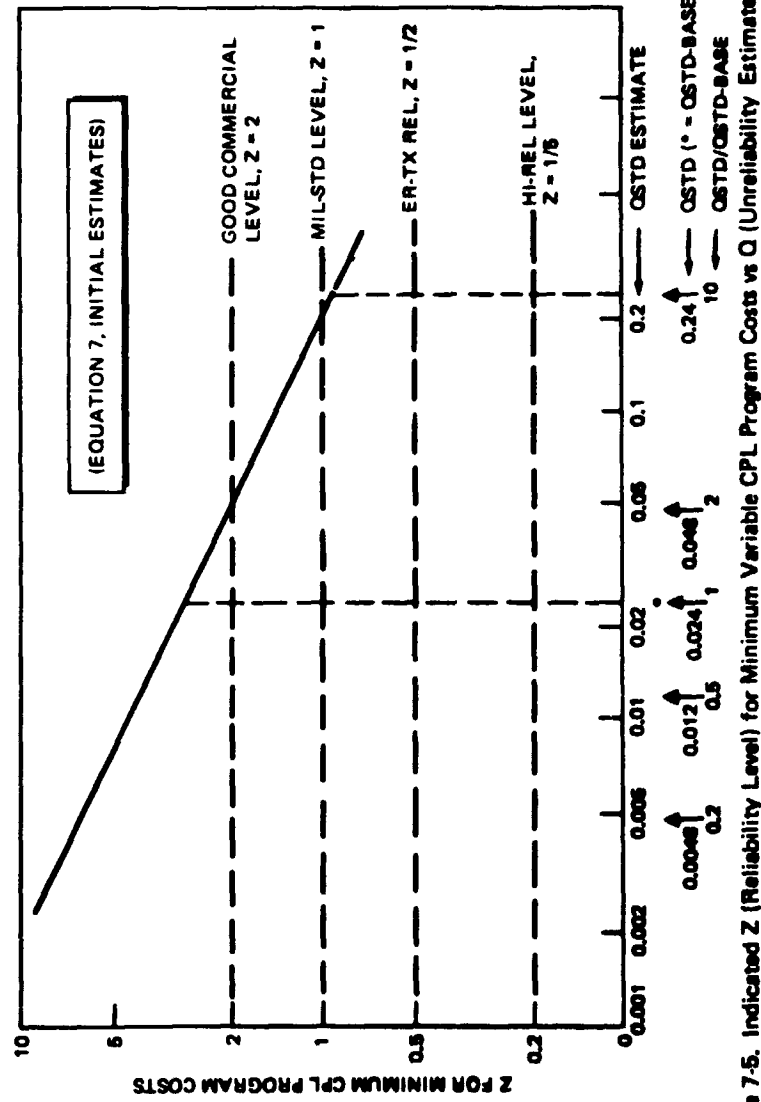
Figure 7-5. Indicated Z (Reliability Level) for Minimum Variable CPL Program Costs vs Q (Unreliability Estimate)
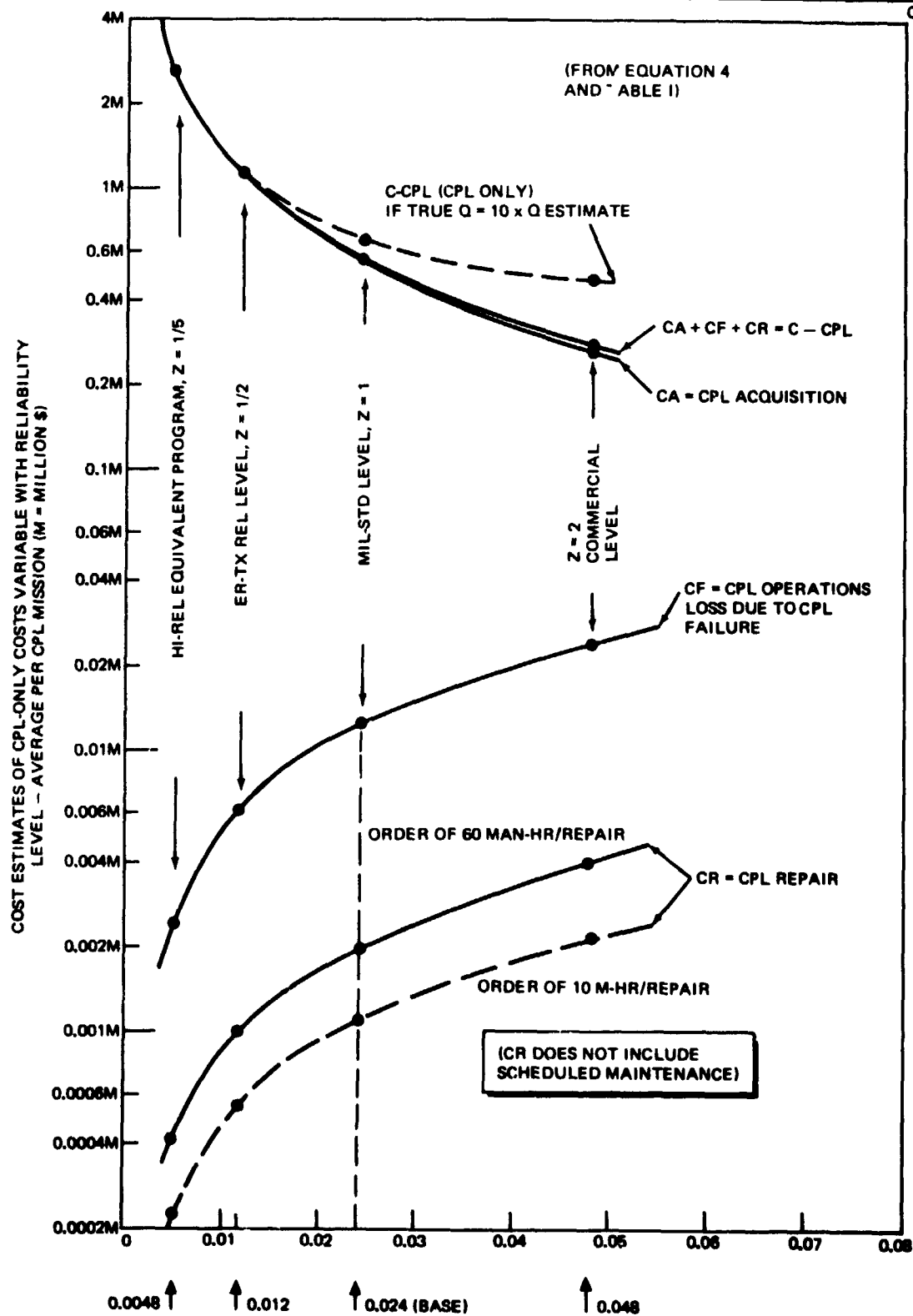
Figure 7-6. CPL-Only Costs per Mission Estimates for Costs Variable With CPL Reliability Level
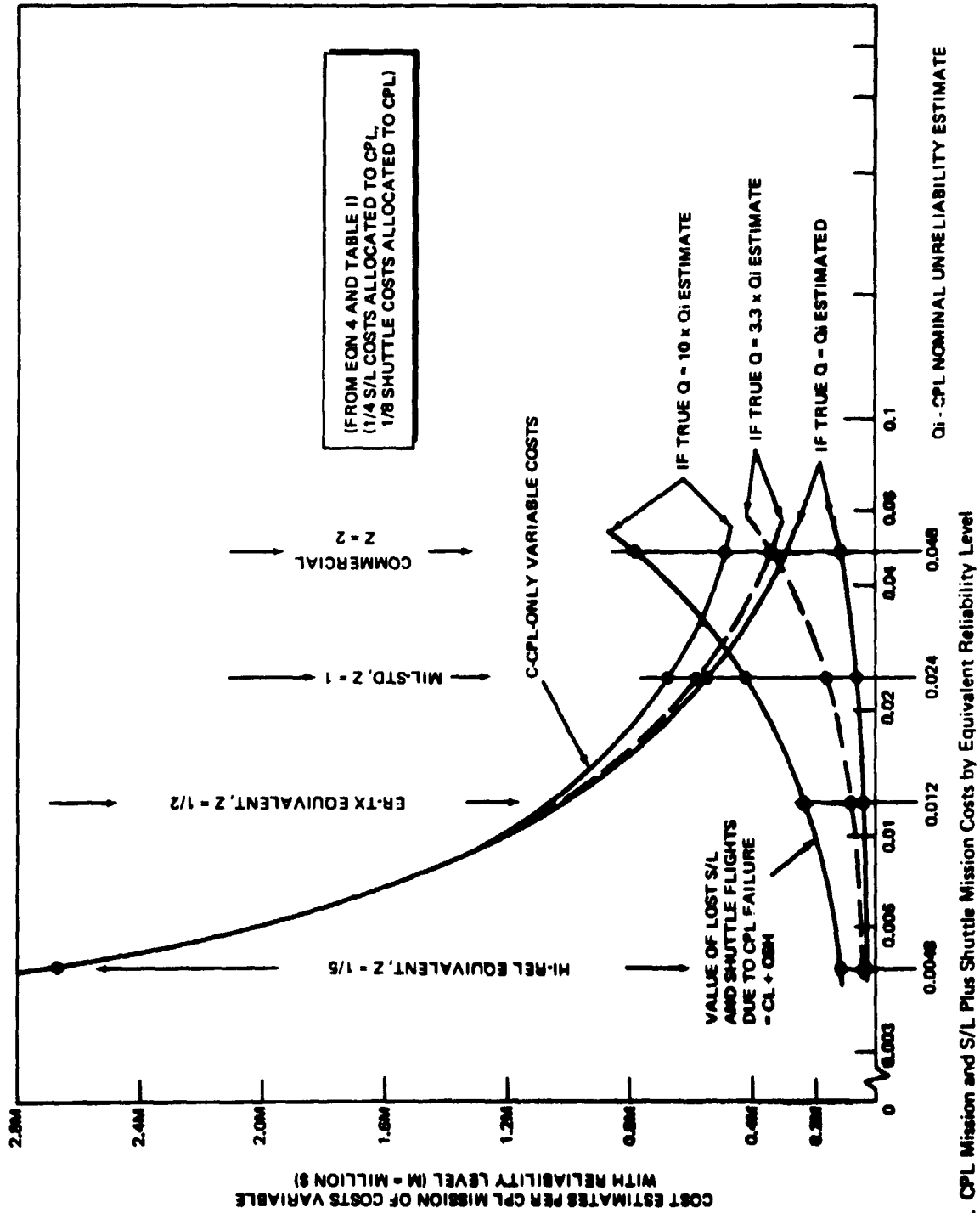
Figure 7-7. CPL Mission and S/L Plus Shuttle Mission Costs by Equivalent Reliability Level

possible variations. One quarter was used as the Spacelab and one eight as the Shuttle flight cost allocations to a CPL mission. A possible error range of one to ten times the initial Q estimate was covered in this and subseqnent figures.

D. The CPL-only and Spacelab and Shuttle allocated costs were combined to form total CPL costs per mission variable with reliability level for a range of Q estimates (illustrated in Figure 7-8).

E. Equation 4 was modified to vary the portion of Spacelab and Shuttle flight costs allocated to the CPL mission (E and G factors were varied in Equation 2). This was tabulated in Table 7-3, and illustrates the effect on indicated minimum costs for a range of Q estimates in Figure 7-9, judged the most significant illustration in this exercise.
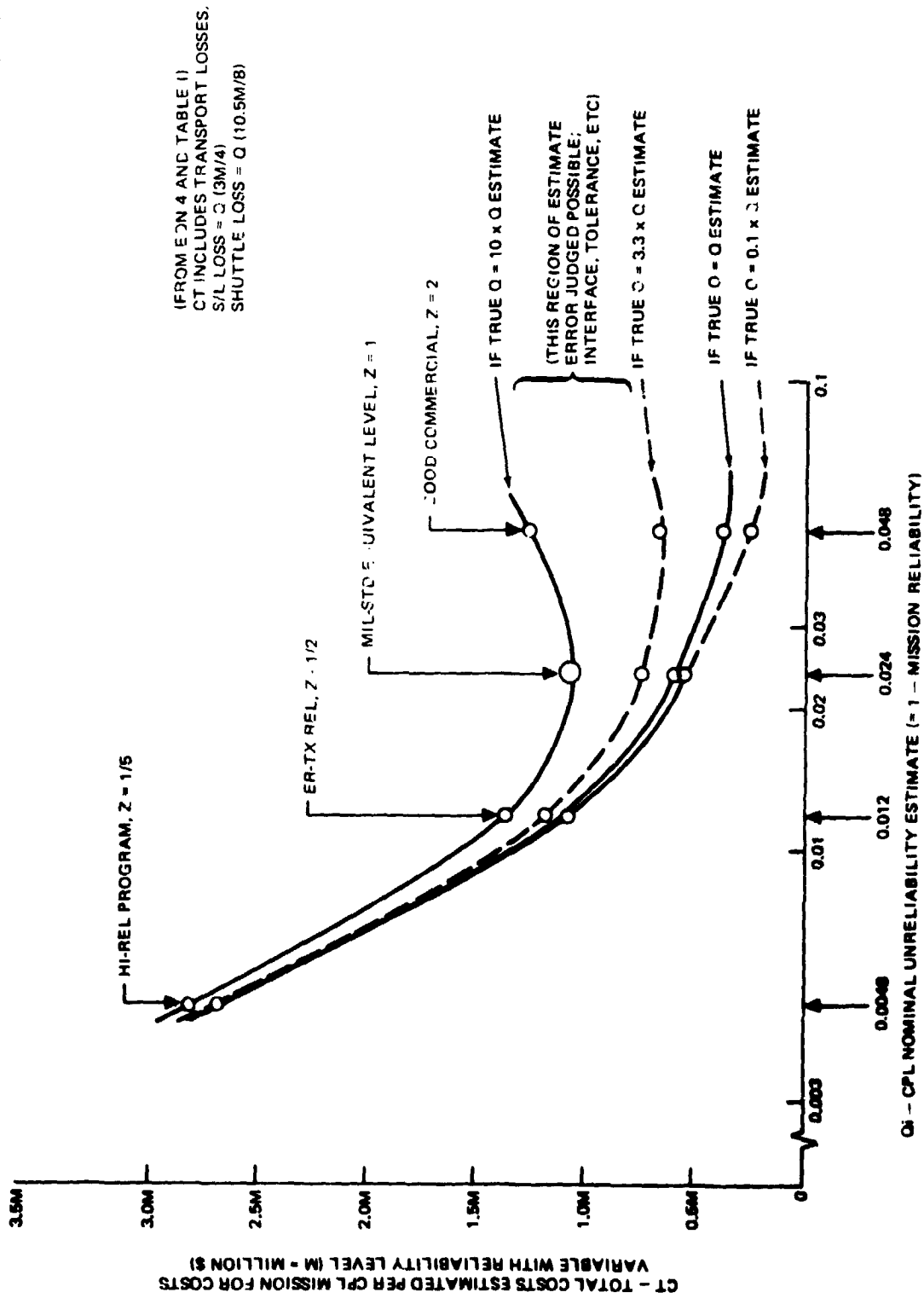
Figure 7-8. CPL Total Mission Cost Estimates by Equivalent Reliability Level

Figure 7-9. CPL Total Mission Cost Estimates of Costs Variable by CPL Reliability Level for a Range of CPL Q Estimates and S/L and Shuttle Allocated Costs

7. ., 4 <u>Observations, Conclusions, and Recommendations</u>

7.3.4.1 Reliability Level — Acquisition Cost Estimator

The "Z" estimator of Figure 7-4 gave reasonable trends of CPL acquisition costs with reliability level variations.

7.3.4.2 Minimum Cost Reliability Level Indicator

The Figure 7-5 plot of Equation 7 for minimum cost "Z" reliability level compared well, as it should, with the indications of the Figure 7-8 plot of Equation 4 variations. In both illustrations, Spacelab and Shuttle allocated flight costs were 1/4 and 1/8 of total, respectively.

7.3.4.3 CPL-Only Program Costs

When CPL-only costs were considered, as in Figure 7-6 (illustration of portions of the Table 7-3 estimates), the apparent conclusion was that the CPL should be aimed at a commercial level, low acquisition cost program. Safety considerations impacted such a conclusion in some equipment areas.

7.3.4.4 Corrective Maintenance-Repair Costs

The costs of corrective maintenance for CPL equipment malfunction repairs were not expected to be a significant portion of program cost estimates as illustrated in Figure 7-5, even for mean-times-to-repair considered quite high (on the order of 10 to 60 man-hours per repair). Following maintainability design principles considered reasonable and normal should suffice considering the corrective maintenance impact on total program costs.

7.3.4.5 Scheduled Maintenance Costs

Scheduled maintenance costs, such as configuration changes, servicing, calibration, refurbishment, or overhaul, were expected to be the significant program costs where the benefits of good maintainability design and procedures were significant. Such costs were judged to be not variable with CPL reliability level and, therefore, were not included in the relationships used in this exercise. They were considered part of the basically fixed costs

which form a floor to the costs variable with reliability level estimated for this exercise, though such maintenance costs should be quite sensitive to changes in maintainability or other parameters.

7.3.4.6 CPL-Only Costs and Spacelab and Shuttle Costs

If 1/4 of the Spacelab flight costs and 1/8 of the Shuttle flight costs were charged to a CPL mission, such expected lost costs due to CPL failure became significant as illustrated in Figure 7-7. Some charge for transportation costs or fare was a reasonable approach in searching for a least-cost program. No attempt was made in this exercise to include interest and time factors to relate average mission costs to present worth or related values since such were judged unnecessarily precise in this preliminary analysis.

7.3.4.7 Total CPL Mission Variable Costs and Recommended Reliability Level

Figure 7-8 (in combining the Figure 7-7 CPL and Spacelab plus Shuttle flight costs) indicated that if the initial Q (unreliability) estimate based on a MIL-STD equivalent program of 0.024 were true, the minimum cost point was for a commercial equivalent level program (higher Q, lower reliability and cost). However, such initial Q estimates based on gross equipment and parts estimates was expected to increase. Also, for a two-system program in an environment that can be expected to be extremely economy conscious, it can be expected that the resources and time will not be available for the extensive analysis, testing, and redesign needed to totally eliminate the interface and tolerance interaction potential problems that will arise in the development and integration of a mix of instrumentation such as the CPL. A final Q of on the order ten times the initial estimate is possible. Figure 7-8 indicates that if the resulting Q should include that 10X degradation or Q estimate error factors, the CPL should be developed under a program at least as stringent as a MIL-STD equivalent program. The actual program should be some mix of good commercial items where their performance under the expected environments is reasonably assured, MIL-STD equivalent parts and procedures as a general practice, and relatively stringent reliability evaluation and controls on components considered suspect,

critical to mission success or crucial to safety. This exercise at the present development stage did not attempt to make various reliability level recommendations to specific subsystems or equipments.

7.3.4.8 Total CPL Mission Variable Costs with Transportation Cost Charges

Figure 7-8 illustrates the effect on the minimum-cost Q for combinations of variations in the Q estimate error (one times to ten times initial estimate) and in the portion of the Spacelab and Shuttle flight costs allocated to a CPL mission. As larger portions of the Spacelab and Shuttle flight costs are allocated to the CPL, the Q or reliability level of the CPL program should increase to more extensive and expensive programs to achieve a minimum CPL program cost.

7.3.4.9 CPL Reliability Level

The results of the study indicate that while the overall CPL need not be directed at a high reliability program such as appropriate to systems crucial to men's survival or to long-duration space probes, it should not be directed at the least expensive collection of equipments possible. As in most questions, the best target is somewhere between the extremes.

7.3.4.10 Reliability Goal and Preliminary Allocations

A CPL MIL-STD reliability level equivalent program for minimum program costs can be expected to yield CPL mission success reliability of from 0.98 to 0.8. Since a major uncertainty is the degree of degradation to be caused by interface interactions, a logical CPL goal would be 0.98 with the expectation that allocations to individual subsystems and equipment based on the 0.98 would not include the interface factors. Therefore, such interface factors would degrade the CPL resulting reliability below the 0.98 product of the subsystem reliabilities but still result in an acceptable CPL reliability result. Figure 7-10 gives the CPL cost as a function of reliability level.

7.3.4.11 Future Reliability Allocations

Allocation to subsystems and equipments when subsystem definition is expanded should certainly be more equitable than the equal unreliability
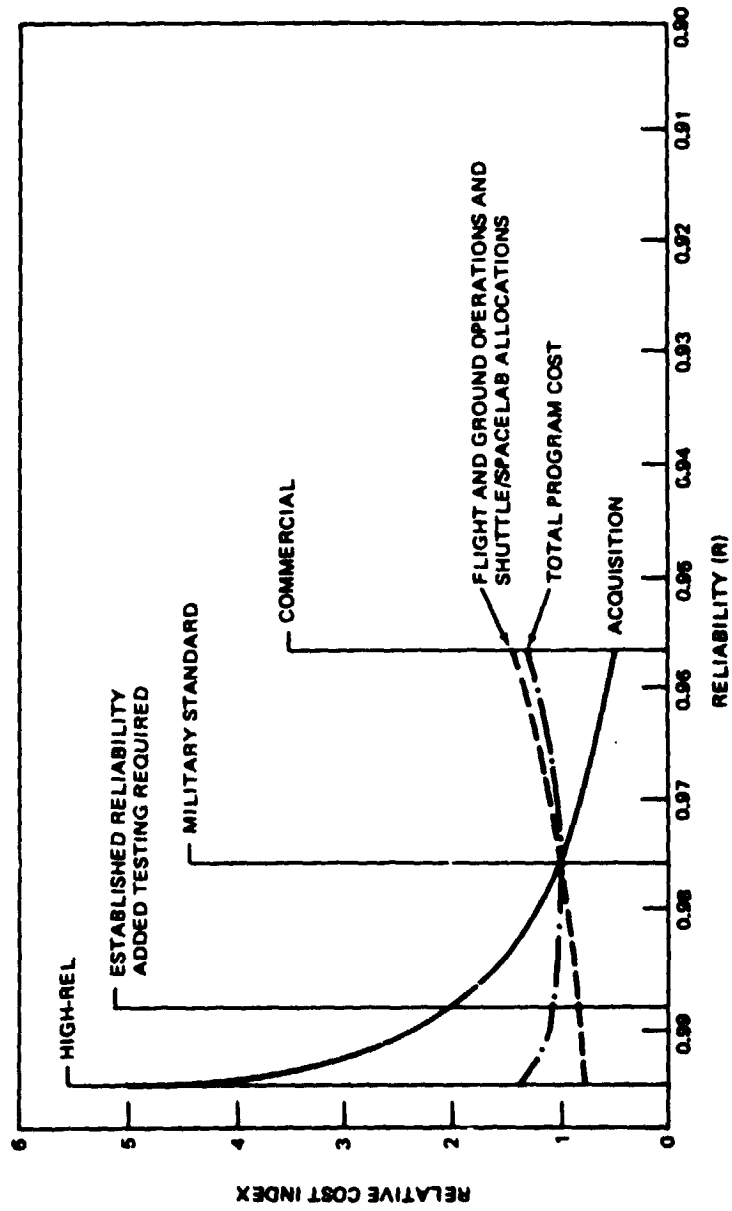
Figure 7-10. CPL Cost as a Function of Reliability Level

distribution to subsystems. Future allocation should consider expected
reliability based on relative complexity or sensitivity to environments,
operating time per mission, portion of total missions on which used, signi-
ficance or criticality to mission success, redundancy or alternate paths to
acceptable performance including the practicality of in-flight maintenance,
and safety impacts.

7.3.5 CPL Program Cost — Reliability Relationships

Relationships used to relate changes in total CPL program cost to CPL
equivalent reliability levels are described below.

The total CPL program cost would include at least the following factors:

Cost Total =   CPL   + CPL +   CPL   + Spacelab   +   Shuttle
            Acquisition   Flight   Ground   Allocation   Allocation
                             OPS   OPS

DDT&E	Launch	CPL Repair	Transport fare,
Production	Support	Service,	CPL portion
	In-Flight Repair	refurbish,	
	(Negligible)	overhaul,	
	Damage to CPL,	transport,	
	Spacelab, Shuttle	reconfigure,	
	(Assume None)	calibrate	
		GSE-Facilities	
		Data Reduction	
		Crew Train	
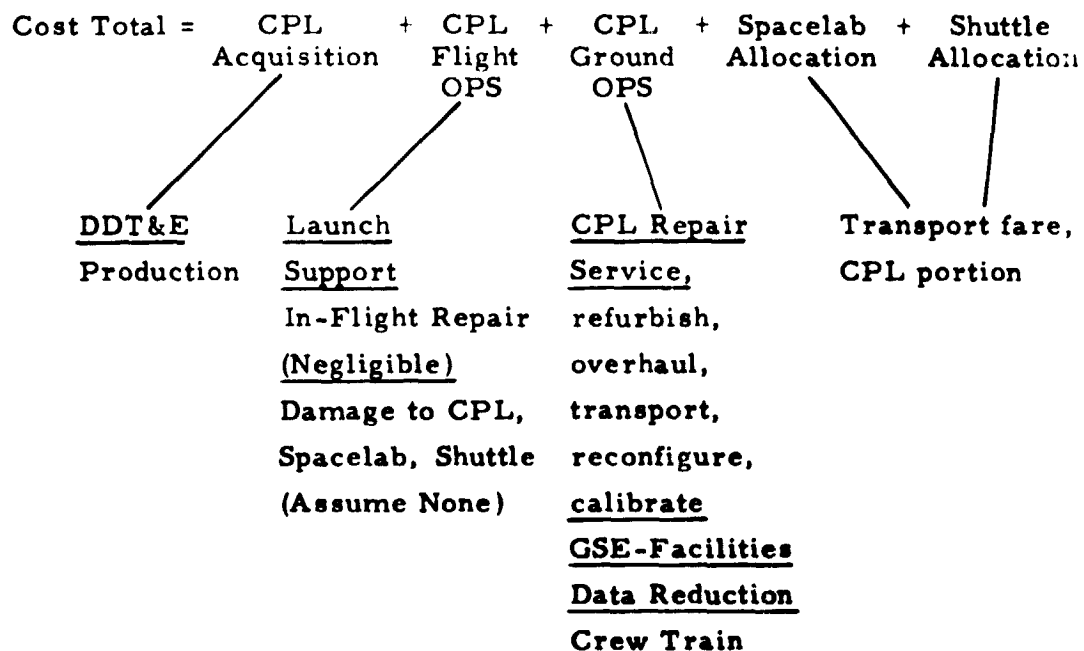
To estimate relative program costs as a function of reliability levels, we
need not consider costs that will remain essentially constant. Here we
assume that costs such as servicing, reconfiguration, or overhaul will not
vary significantly with reliability level or unreliability, the expected failure
probability per mission or period. A low failure rate obtained by large
safety margins might delay wearout and reduce overhaul rates, but such is

assumed negligible variation here. Therefore, the relationships below concern costs variable (above some base level) with equivalent program reliability/unreliability level to indicate appropriate target reliability levels.

The relationships do not attempt to evaluate the contractor production added costs of rework and retest at assembly and higher levels potentially incurred due to low reliability incoming parts, although such costs can be significant, particularly on complex units or high quantity production.

The following symbols and factors are used in the cost-reliability relationships.

$C1$ = Total CPL program acquisition (DDT&E + production) costs = $CSTD/Z$.

$CSTD$ = Total average CPL. MIL-STD equivalent program acquisition costs.

A = Total CPL's (2 used).

D = Missions per CPL (21 used, 10 years, 6 months between missions).

Q = CPL unreliability.

Qi = $QSTD(Z)$ = CPL Q at a reliability level related to Z.

Z = Reliability level factor = $Qi/QSTD$ = $CSTD/Ci$

$QSTD$ = Q estimate for a MIL-STD equivalent CPL program, including estimate variation from the initial nominal estimates.

$QSTD$ (Base) = Initial or nominal estimate of Q for a MIL-STD CPL program (0.024 here).

CO = CPL average flight and ground operations cost per mission (assumed essentially constant with varying reliability level — 0.5M used).

fm = Ground repairs per mission include flight and approximately 6 months ground period induced failures (estimated as $8 Qi$ or $8 Xi$, or $8 ZXSTD$; eight times the expected flight failures).

$XSTD$ = CPL expected failures per flight (approximately = $QSTD$ if $Q < 0.1$)

CH = Cost per repair (initially estimated as 0.01M to include parts, labor, transport, calibration).

CL1 = Spacelab (S/L) average flight cost, less experiments (estimated as 5M - 2M exper. = 3M).

E = Factor for S/L flight cost allocated to CPL as transport fare (used 4 initially).

$$\frac{5 \text{ days} \times 2 \text{ shifts} \times 2 \text{ men/shift}}{5 \text{ days CPL} \times 1 \text{ shift} \times 1 \text{ man}}$$

$$= \frac{\text{S/L man-days/mission}}{\text{CPL man-days/mission}} = 4$$

CS1 = Shuttle average flight cost.

G = Factor for Shuttle flight cost allocated to CPL (used 8 initially).

CT = Total average CPL program costs per mission variable with reliability level.

$$CT = \frac{C1}{AD} + QCO + Fm(CH) + Q(CL1/E) + Q(CS1/G) \qquad (1)$$

$$CT = \frac{(CSTD)}{ZAD} + Z(QSTD)\,CO + 8Z(XSTD)\,CH$$

Total Variable Cost (Per Mission)	CPL Acquisition	CPL Lost Mission Costs Due to CPL Failure	Repair Costs

$$CT = CA + CF + CR \qquad (2)$$

$$+ Z(QSTD)\,(CL1/E) + Z(QSTD)\,(CS1/G)$$

S/L and Shuttle Lost mission costs due to CPL Failure

$$+ CL + CSH$$

Equation (2) is the basic relationship used in this exercise. For initial estimates before varying some parameters, equation 4 was used.

$$CT = \frac{22.2M}{Z(2)(21)} + Z(QSTD)(0.5M) + Z(XSTD)8(0.01M)$$

$$+ Z(QSTD)(3M/4) + Z(QSTD)(10.5M/8) \tag{3}$$

$$CT(M) = \frac{0.53}{Z} + Z(QSTD)(0.5M) + 8Z(XSTD)(0.01)$$

$$+ Z(QSTD)(0.75) + Z(QSTD)(1.3) \tag{4}$$

For an indication of best Z or reliability level program to verify the results of Equation (4), the traditional technique of differentiating Equation (2) with respect to Z, equating the result to zero (slope) and solving for Z yields Equations (6) and (7) (substituting QSTD for XSTD in the low-impact repair term).

$$\frac{\partial CT}{\partial Z} = \frac{1}{-Z^2}\frac{CSTD}{AD} + (QSTD)\ CO + 8(QSTD)\ CH + (QSTD)\ (CL1/E$$

$$+ CS1/G) = 0 \tag{5}$$

$$Z = +\left[\frac{CSTD}{AD} \middle/ \left[(QSTD)\ CO + 8(QSTD)\ CH + (QSTD)\ (CL1/E + CS1/G)\right]\right]^{1/2} \tag{6}$$

For initial estimates,

$$Z = +\left[\frac{0.53}{QSTD\ (0.5 + 0.08 + 0.75 + 1.3)}\right]^{1/2} = +\left[\frac{0.2}{QSTD}\right]^{1/2} \tag{7}$$

For the indicated optimum Z — reliability level for range of Q estimates, see Figure 7-5.

7.3.6 CPL Reliability Initial Goals and Subsystem Allocations

Based on a CPL program directed at program activities resulting in a MIL-STD equivalent or better reliability level program, the following range of reliability-related measures are estimated for an average 40-hour operation CPL mission, including potential interface/tolerance-interaction degradations.

	Good	Average	Poor
CPL Mission Reliability	0.98	0.89	0.8
CPL Unreliability	0.02	0.11	0.2
Expected Failures/Mission	0.02	0.12	0.22

The following lists the recommended CPL reliability goal with a simple preliminary allocation to subsystems for early planning of equally distributed Q (unreliability). The bulk of interface/tolerance-interaction problems are assumed to outside or beyond the allocations that are budgeted to equipments, so the goal is recommended at the high estimate to allow for acceptable total CPL reliability degradation beyond the product of equipment allocated reliabilities.

7.4 MAINTAINABILITY ANALYSIS

This section provides preliminary guidance and recommendations concerning maintainability goals that remain applicable through subsequent program phases. The recommendations result from assessment of components, assemblies, subsystems and functions having the potential of causing maintainability concerns in design or operations. The assessment includes consideration of safety, reliability and test evaluations and of program cost impacts.

Recommendations drawn from the analyses in this section include:
A. Retain the MIL-STD level of reliability.
B. CPL checkout, maintenance, and refurbishment should be done outside the Spacelab.

C. Provide access through front panels for any potential on-orbit repairs.

D. Since maintenance and refurbishment costs represent a small portion of CPL total operations cost, they are not primary concerns. However, the cost sensitivity of the other elements of total operations cost should be evaluated to explore evident and latent opportunities for cost reduction.

7.4.1 Approach

7.4.1.1 General

The maintainability approach is directed toward achieving a design that is (1) testable to maximize verification that the subsystems have not failed and to identify what is failed or degraded; (2) repairable at a level to minimize field station equipment, time, and skills; and (3) economical with regard to refurbishment of structure and failed or wear out (limited life) items. Most of the effort to achieve these objectives is encompassed in the M analysis.

The M analysis provides evaluation for each item of equipment, determining its mission required preventive (scheduled) maintenance requirements and corrective maintenance methods, and selectively recommending design corrective action as required to achieve operational objectives. As each design area achieves proper M design quality, the maintenance tasks are documented to show repair policy for each item, predicted frequency, and predicted task time. The initial predictions are available at Preliminary Design Review (PDR). The process is iterative, and the data used for system predictions are improved and verified by later data as available.

The key to an effective maintainability test program is the ability to use maximum routinely available data to verify the predictions made in analyses and thus minimize costs of tests. The analysis identifies all repairable/replaceable items and risk or frequency of occurrence. The collected data on a number of tasks or task elements verify the accuracy of these individual predictions and demonstrate the actual access and replaceability of components and visual study are inconclusive. Thus, the Functional Model (FM), the Project Verification Model (PVM), and the Flight Test Article

(FTA) will provide early opportunities to determine actual functional test and fault isolation times. These elements of the total repair time are combined with untested tasks (i. e., replace-time predictions) to update the repair-time prediction. The verification data are collected and analyzed by M engineers without introducing mechanic work tasks.

The tests on the Functional Model (FM) will determine critical access problems early enough to incorporate required changes in the design prior to Critical Design Review (CDR). These tasks will be conducted by mechanic personnel to verify access with some indication of remove/replace task time. The actual operations of acceptance test, checkout, and repair of failures for the Flight Test Article (FTA), and production flight articles will provide an update of frequency and maintenance time. These data and those available from maintenance procedure verification on the FM, PVM and FTA will be collected by observation and analysis of actual operations rather than by scheduled M demonstrations.

The measure of M actual performance is provided by the system predictions utilizing approved models and detail task time data verified by and updated to incorporate the observed data from system tests and operations. The predictions will reflect maintenance tasks conducted according to formal procedures and the best prediction of frequency. The M predictions will identify critical tasks to achieve system operational status, down times for unscheduled maintenance during CPL turnaround, the recommended spares levels for each critical subsystem item for field station stocks. These data are integrated with the logistics studies of scheduled maintenance, servicing, and pipeline handling of repairables to form the total viable maintenance and refurbishment plan.

Maintenance procedures are developed after the definition of maintenance requirements through maintainability and maintenance analyses. The verification of these procedures on a functional model or development fixture provides an initial opportunity to determine their validity in a semi-realistic environment. The test objectives include the verification of:

- Satisfactory accessibility
- Ease of Line Replaceable Unit (LRU) replacement
- LRU handling capability

- Potential safety hazards
- Identification of proper tools
- Maintenance manhours
- Manpower requirements

This is first conducted as a contractor DDT&E function and subsequently by NASA an an Initial Operational Test and Evaluation (IOT&E) effort.

7. 4. 1. 2 Specific

A preliminary Maintainability (M) evaluation has been made for the Laboratory Subsystems. These subsystems which will be incorporated into a console and installed within the Spacelab, warrant careful design attention to assure ease of maintenance and repair. A qualitative evaluation of the remaining subsystems/assemblies indicates that they are of a general "plug-in" nature and are not candidates for Spacelab or CPL M controls at this time.

The M analysis for the above listed subsystems/assemblies estimated the number of men and time required for repair at the maintenance facility during refurbishment. Three codes have been used to reflect life characteristics, in lieu of estimates of lifetime:

Code 1 — Items that are subject to some wear-out phenomenon with use. Characteristic life times for these items exceed the expected usage of a single Spacelab in the Shuttle Program (1973 Mission Model), and only routine inspection, lubrication, and adjustment monitoring are e ected as preventive maintenance actions between flights.

Code 2 — Items that are not subject to degradation with use. They require no preventive maintenance other than inspection for accumulation of waste debris, moisture, and wire clearances.

Code 3 — Items which may require some on-orbit action to improve operations; for example adjusting the wick condenser, or cleaning mirrors.

The estimates assume that all assemblies, subassemblies, and components are subject to random failure with respect to time. The repair times are the estimated down times to fault isolate and repair the CPL equipment

when installed in the Spacelab. Failure of any of the assemblies, subassemblies and components have been considered a single failure. The access time represents the removal of the console. Contingency time constitutes administrative time for systems requiring draining/safing/purging prior to work.

The reliability studies have shown that the cost effective solution to the design for a five-day mission is achieved through reliability options. A long term mission (>20 days in space) will probably introduce requirements for on-orbit maintenance. Quantitative maintainability analyses introduce the following formula to predict corrective maintenance requirements:

Expectation of corrective maintenance -

$$\epsilon_{mi} = \epsilon_i \cdot A_{fi} \cdot C_{fi} \cdot E_{fi}$$

where:

ϵ_i = NλKT = Expected failures of the ith component/subassembly

N = Number of ith components

λ = Failure rate

K = Stress factor - environmental

T = Operating time or cycles per mission

Note $e^{-\epsilon_i}$ = Reliability of ith component (probability of zero failures)

Expectation of corrective maintenance (Definition continued)

A_f = Anomaly factor - number of component/removals during CPL refurbishment to correct for component degradation that did not cause mission failure but makes the component unusable for further missions. $(1 < A_f < 9)$

C_f = Criticality factor - essentially to the mission - $(C_f = 0$ to $1)$. A C_f value is assigned for on-orbit as well as for ground maintenance to help determine space maintenance critical times.

E_f = Error factor - maintenance time and cost modifier based on judg-
ment as to the ratio of incorrect initial removals due to improper
failure diagnosis and fault isolation. This varies with options in
test features (test efficiency) and test equipment. (E_f = 1 to 3)

For on-orbit maintenance considerations, A_f = 1

This method for estimating maintenance actions is customary and appropriate
for Phase A subsystem design and development, and provides an early
indication of capability of the design. The next study phase, Phase B, should
include a task to update the analysis by predicting maintenance man-
hours (MMH) and elapsed time based on actual reliability estimates for the
components and a more detailed evaluation of maintenance and repair methods
and times.

7.4.2 Cost Sensitivity Analyses

The cost sensitivity analyses have been performed in two steps. First,
Maintenance and Refurbishment (M&R) cost sensitivity has been quantified
using the corrective maintenance estimates, as described above, in conjunc-
tion with the following Ground Rules and Assumptions pertaining to con-
tractor M&R functions. Second, contractor M&R cost sensitivity has been
related to total operations cost, including contractor's other operations cost
and principal investigator costs.

7.4.2.1 Contractor M&R Cost Sensitivity

The results of the quantification and attendant sensitivity analyses are
presented graphically summarized in Figure 7-11, Total Maintenance and
Refurbishment Costs for 42 Flights (contractor costs, excluding principal
investigator costs) as a Function of Field Site M&R Manhours Per Flight.
Figure 7-11 graphically shows the sensitivity of an index of M&R costs at
the project level to variation in field site M&R manhours per flight from
10 to 100 manhours. Two operational conditions are reflected. In one
condition, M&R has been charged only for the man hours used, and
Equation (1) has been derived to quantify the M&R cost index from an input
of direct M&R manhours per flight:

$$Y = 0.9903 + 0.000955(x)$$
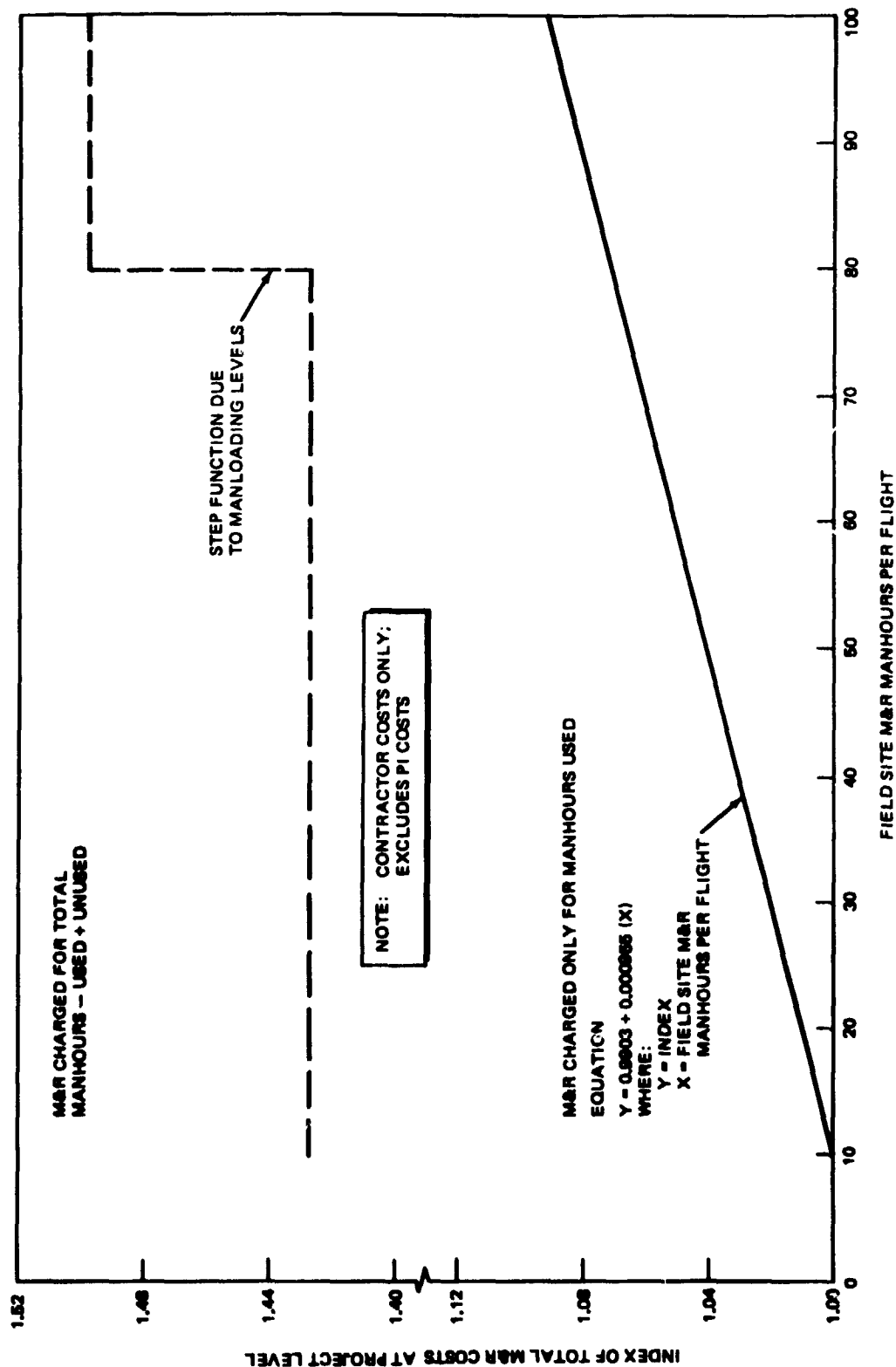
Figure 7-11. Total M&R Costs for 42 Flights as a Function of Field Site M&R Manhours per Flight

where:

Y = Index of contractor total M&R costs at the project level.   (Excludes
    principal investigator costs.)

x = Field site M&R manhours per flight

In the second condition, M&R has been charged for both the used and the
unused M&R manhours.   The cost index for this condition obviously is higher
and variation in the field site M&R manhours per flight results in a graphic
plot that is a step-function due to incremental variation in manloading levels.

7.4.2.2   Conclusions

A. Because of the relatively low launch rate (average = 4 flights/year),
    it is essential that the CPL not be charged for the unused M&R
    manhours.   Charging the CPL for these unused manhours would
    increase M&R costs from 40 to 50 percent (index of 1.000 - 1.08
    versus 1.427 - 1.498).   Stated another way, there is an opportunity
    to reduce M&R costs by 40 to 50 percent, if M&R personnel can
    perform other tasks and charge other budgets when they are not
    performing M&R on the CFL.   These other tasks could include
    maintaining launch site GSE, performing M&R on other payloads,
    and returning to their home plant after each flight.

B. For the case where M&R is not charged for unused manhours:

    1. Labor cost as a percent of total M&R cost varies directly with
        the M&R manhours per flight - 0.9 percent at 10 manhour/flight
        to 8.4 percent at 100 manhours/flight.

    2. Although material cost per flight remained constant, as a
        percent of total M&R cost it varied inversely with the M&R
        manhours per flight - 49.7 percent at 10 manhours/flight to
        45.8 percent at 100 manhours/flight.

    3. Sustaining engineering also remained constant and varied
        inversely with M&R manhours per flight - 47.0 percent at
        10 manhours per flight to 43.3 percent at 100 manhours per
        flight.

4. Project management, representing a level of effort function, has little variation with respect to variable M&R manhours per flight. Expressed as a percent of total M&R cost it varied from 2.4 percent at 10 manhours per flight to 2.5 percent at 100 manhours per flight.

5. Both the labor and material percentages in B1 and B2 above reflect the MIL-STD equivalent reliability (0.976).

6. Since sustaining engineering accounts for most of the remaining portion of total M&R costs (from 43 to 47 percent), an opportunity for cost reduction appears likely in this area. The cost of sustaining engineering has been calculated based on one man full-time over the 10-year period. It is quite probable that sustaining engineering cost could be reduced by about 50 percent or more, if his time could be shared with other tasks, assuming fewer design changes resulting from good initial CPL planning and design, and assuming close PI coordination to assure acceptability/compatibility of the PI's experiments.

7.4.2.3 Cost Sensitivities

Figure 7-12 graphically presents Maintenance and Refurbishment Cost as a Percent of Total Operations Cost for Varying Field Site M&R Manhours Per Flight. Figure 7-12 also shows that the CPL total operations cost is rather insensitive to variation in field site M&R manhours per flight - varying field site M&R manhours per flight by a factor of 10 (from 10 to 100) produces only a 3 percent change in the ratio of M&R cost to total operations cost - from 5.9 to 6.2 percent. This insensitivity seems reasonable in consideration of: (1) the nature of the CPL - it is only a portion of the total experiment payload in the Spacelab; (2) the CPL design approach - simple, functional design employing largely current state-of-the-art components/assemblies adapted from 1-g to 0-g environment; and (3) the CPL reliability goal of 0.976. Similarly, varying the field site M&R manhours per flight from 10 to 100 results in only a 9 percent change in contractor total operations cost for 42 flights. Since the PI operations costs were held constant, the
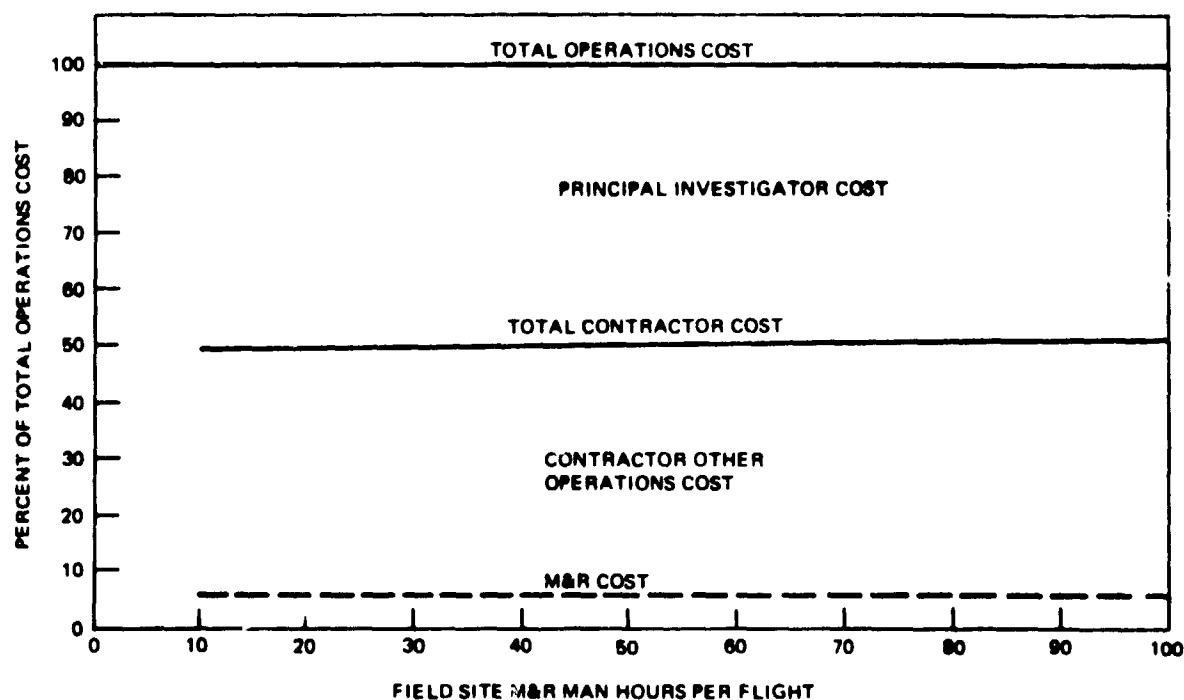
Figure 7-12. M&R as a Percent of Total Operations Cost

variation in field site M&R manhours per flight from 10 to 100 only affected a 4.3 percent increase in total operations cost for 42 flights.

Figure 7-13 has been developed and is a graphic plot of the Index of Total Operations Cost as a Function of Field Site M&R Manhours Per Flight. The chart reflects both the linear relationship of the ordinate and abcissa values and the relatively flat slope of the curve. Equation (2) has been derived to describe the curve:

$$Y = 0.9953 + 0.000466(x)$$

where:

Y = Index of total operation cost at the project level

x = Field site M&R manhours per flight
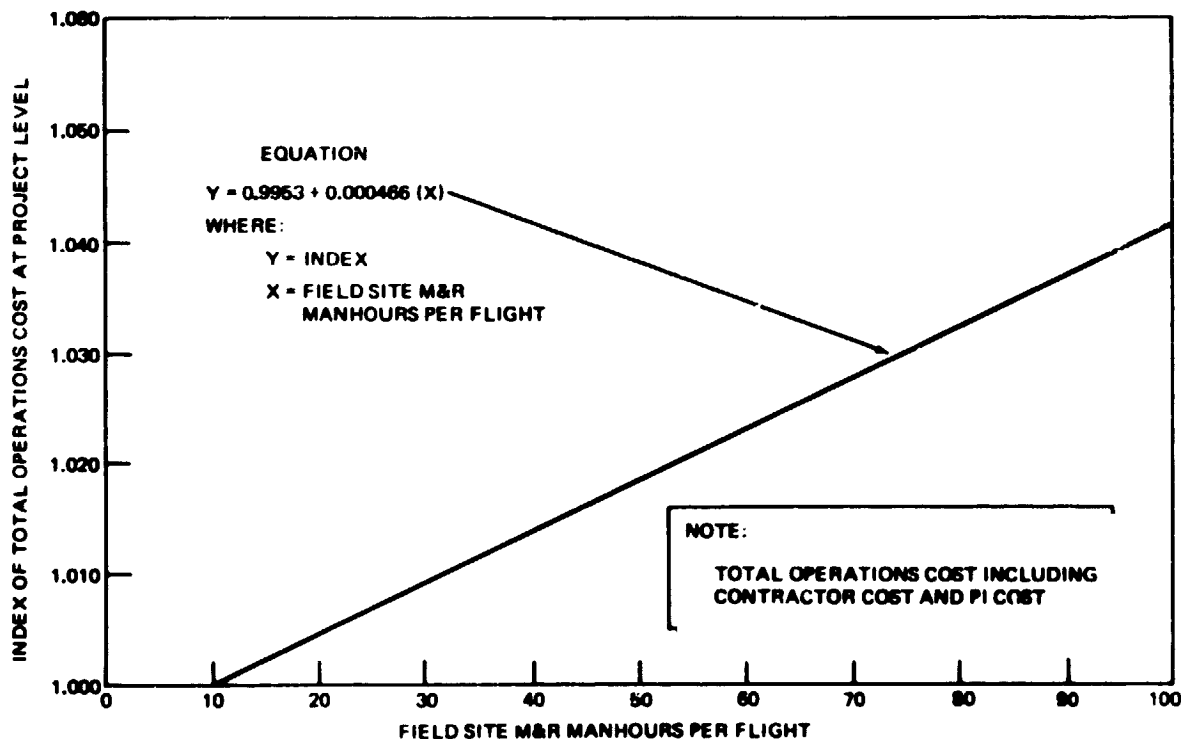
Figure 7-13.Index of Total Operations Cost as a Function of Field Site M&R Manhours per Flight

7. 4. 2. 4 Conclusions

A. Although opportunities exist for reducing M&R costs, as noted above, properly controlled M&R operations will represent a rather small portion of total operations cost. Therefore, total operations costs are relatively insensitive to variation in M&R manhours or costs.

B. Cost sensitivity of the other elements of total operations cost will be addressed partly in this study and, to a greater degree, in the Phase B study.

C. These other elements appear to offer greater opportunities for cost reduction.

7. 4. 3 Recommendations

A. Retain the MIL-STD level of reliability, since this will result in selection of parts and qualification of new components such that

corrective maintenance would be at a minimum during the turnaround/refurbishment cycle. Thus, CPL corrective maintenance should not impact the Shuttle orbiter 160-hour turnaround schedule.

B. Access to the area behind the console will be difficult for any maintenance. It is suggested that any equipment found desirable for on-orbit repair be mounted on the front panel of the console so that it can be removed and replaced easily.

C. From initial review of subsystems, it appears that the console checkout, maintenance, and refurbishment should be done outside the Spacelab. It is suggested that the Orbiter-to-CPL interface connectors (fluids and electrical) be installed in a panel that is bolted to the Spacelab shell and is removed as a part of the console. The CPL console to Spacelab subsystem interface connectors should be placed in an easily accessible location. Access can be from either side, however, access through sealed doors through the pressure shell (common location in the shell for all payloads) will minimize interior work interference.

D. Preventive maintenance man-hours (checkout and refurbishment) during turnaround have not been estimated in detail. This time can be minimized by careful evaluation of actually required work. This is very critical in that the time between scheduled CPL flights will tend to make assignment of work to continuously assigned specialists inefficient. With proper storage methods to reduce effects on subsystem damage (dry seals, moisture, dust, etc.) the average corrective maintenance work load probably will not exceed 10 man-hours per CPL flight. This careful storage will reduce subsystem refurbishment costs. Modification costs are a function of extent of change for individual flights. A standard interface design should be provided so that individual experimenter's equipment can be mounted late in the refurbishment cycle, or in orbit, without need for access to the rear of the console.

E. Since M&R represents such a small portion of CPL total operations cost, evaluate the cost sensitivity of the other elements of total operations cost and explore evident and latent opportunities for cost reduction.

Section 8
SUPPORTING RESEARCH AND TECHNOLOGY

8.1 ASSESSMENT AND RECOMMENDATION

An assessment of the Cloud Physics Laboratory SRT has been performed.
This assessment was weighted to reflect the requirements of the current
definition, evaluated from the standpoint of schedule and cost factors, and
ranked from an overall payload viewpoint. This approach was followed to
provide a perspective of the SRT items, and the results are presented in
Table 8-1. The headings of Table 8-1 are explained in the following sections.

8.2 TECHNICAL ASSESSMENT

The detailed SRT data sheets have been formulated by the appropriate sub-
system personnel in conjunction with the Project Scientist. In addition to
the description, technology, benefits, schedule and cost factors provided,
initial weighting factors were established. These weighting factors or
rankings fall into three general categories:

8.2.1 Priority

1. **Mandatory** – SRT tasks which must be completed, or else there will
    be a significant risk in achieving performance and/or schedule
    requirements. These tasks are critical to the success of CPL
    buildup and initial operational capability (IOC).

2. **Desirable** – SRT tasks which are considered beneficial and/or cost
    effective, i.e., a small initial investment would achieve one
    or more of the following: increased reliability; decreased
    weight; improved or more efficient operations; lower cost.
    However, these SRT tasks are not critical and, therefore,
    could be excluded if there were severe budget restrictions.

Table 8-1

ZERO-GRAVITY CLOUD PHYSICS EXPERIMENT LABORATORY

SRT ASSESSMENT

SRT	SRT Title	Category	Priority	Ranking
1	Particle Injector and Size Conditioner	AD*	Mandatory	1
2	Chamber Wall Subassembly	AD	Mandatory	2
3	Acoustical Subassembly	AD	Mandatory	3
4	Electric Field Subassembly	AD	Mandatory	4
5	Optical Subassembly	AD	Mandatory	5
6	Cloud Optical Characterizer	AD	Mandatory	6
7	Water Wicking Surfaces	AD	Mandatory	7
8	Earth Simulation Model	AD	Mandatory	8

*AD = Advanced Development

· <u>Potential</u> — SRT tasks which appear promising, but do not seem to offer quite the same or degree of improvements of those tasks in Priority 2 to warrant a substitution. However, further effort could result in their replacing the approach taken in the baseline.

8.2.2 Cost

SRT costs are the estimated 1974 dollars for performing the SRT tasks described on each respective detailed data sheet. Costs to perform SRT tasks associated with other categories are not included. For example, if one SRT task is in the Advanced Technology category, there will be a cost estimate for performing the Advanced Technology task. If additional SRT work is required in the Advanced Development category and perhaps Supporting Development work will be required at a later date, each of latter SRT categories will be identified on a separate detailed data sheet which has its own cost estimate.

8. 2. 3 Schedule

The SRT schedule is the estimated time in months for performing the SRT task described on each detailed data sheet. Schedule times for performing tasks associated with other SRT categories is not included. For example, if one SRT task is in the Advanced Technology category, there will be a schedule for performing the Advanced Technology task. If additional work is required in the Advanced Development category and perhaps some subsequent Supporting Development, each of these latter SRT categories will be identified on a separate detailed data sheet which has its respective schedules.

8. 3 PROGRAMMATIC ASSESSMENT

The programmatic assessment was performed using the schedule relationship between the Cloud Physics Laboratory and the SRT activities shown in Figure 8-1. The starting dates for each of the SRT categories are purposely not extended in the project in an effort to minimize cost. Items could be initiated earlier than shown and completed in low risk areas; however, the earlier the start, the greater the risk that the design effort may have pr ceeded on a different approach. Premature false starts can increase pr ect cost. Conversely, sufficient data must be available for meaningful design effort and these data can only be obtained by the performance of SRT efforts. Increased project development and production cost, slippage of project schedule and experiment timeline inefficiency (increased operations cost) can result if these data are not available. For the unique Cloud Physics Laboratory equipment it is deemed reasonable, practical, and cost effective to initiate specific SRT efforts on schedule to permit support of design efforts. In general, to minimize development risk for the project, Research (R) should be completed prior to Phase B, Advanced Technology (AT) should be completed prior to Phase C start, Advanced Development (AD) should be completed prior to Phase D start and initiation of the Preliminary Design Review (PDR), and Supporting Development (SD) on alternate approaches should be terminated prior to completion of the Critical Design Review (CDR) as shown in Figure 8-1.
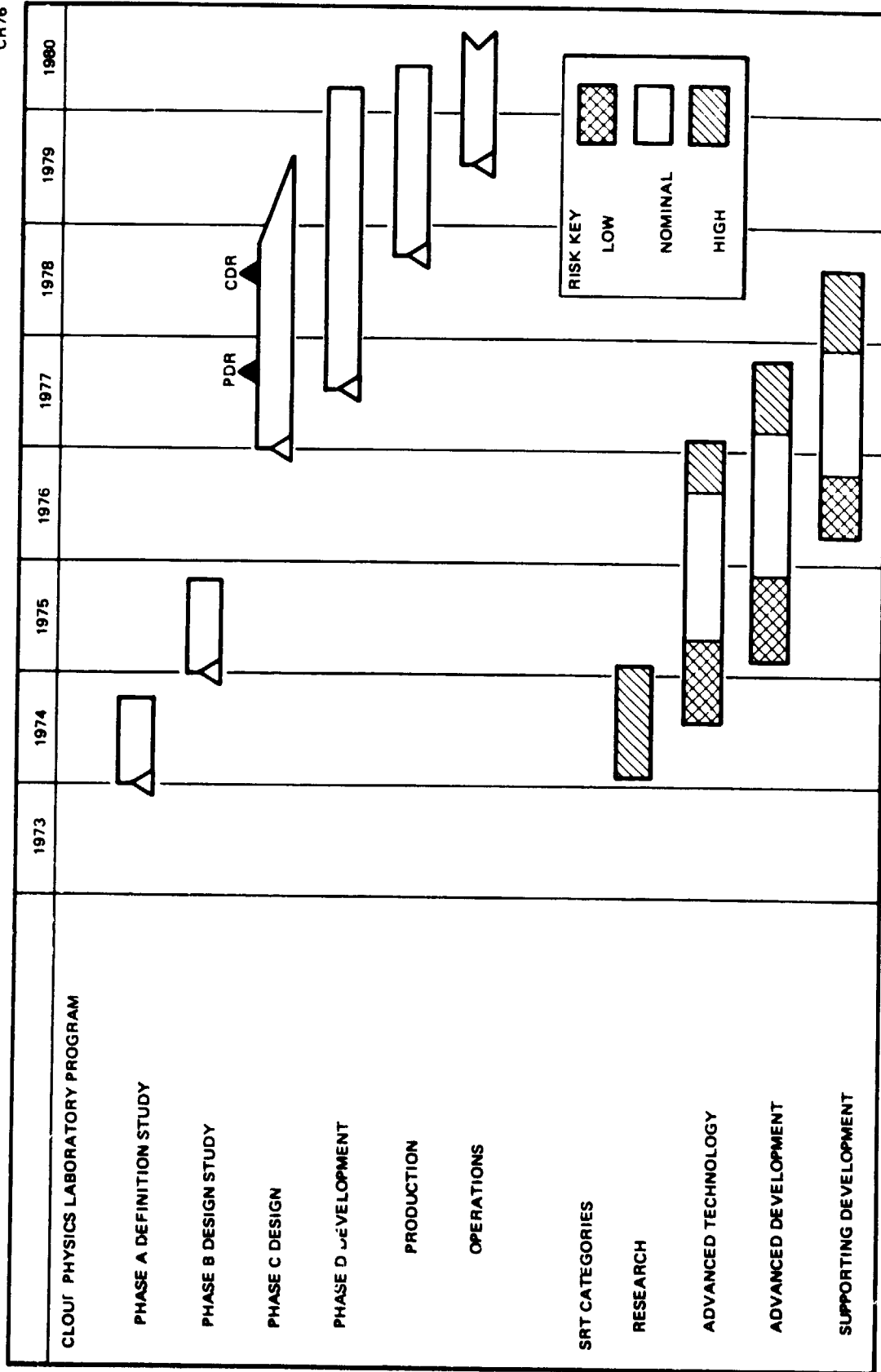
Figure 8-1. Schedule Relationship Cloud Physics Laboratory Development and SRT

8.3.1 Schedule Risk

Schedule risk classification is determined by comparing the SRT task schedule to the Cloud Physics Experiment Laboratory baseline schedule and its constraints (reference attached schedule comparison). In general, the following definitions apply, although specific exceptions may arise.

SRT Category	Schedule Risk		
Research (R)	High	-	Assumes programmatic implications.
		-	If completion is scheduled after start of Phase B.
		-	If the research is Mandatory (Priority 1).
Advanced Technology (AT)	High	-	If AT is Mandatory.
		-	If completion is scheduled after start of Phase C.
	Nominal	-	If AT is Desirable (Priority 2)
		··	If completion is scheduled prior to start of Phase C.
		-	If AT task appears to benefit Phase A and Phase B activities.
	Low	-	If AT is Potential (Priority 3)
		-	If completion is scheduled significantly before start of Phase C.
Advanced Development (AD)	High	-	If AD is Mandatory (Priority 1).
		-	If completion is scheduled after start of Phase C, but prior to PDR.
		-	If AD task appears to offer limited benefit to overall Phase C activity.
	Nominal	-	If AD is Desirable (Priority 2).
		-	If start is prior to Phase C and completion is scheduled prior to PDR.
		-	If the task appears to offer moderate benefit to overall Phase C activity.

	Low	-	If AD is Potential (Priority 3).
		-	If both start and completion are scheduled prior to start of Phase C.
		-	If the task appears to offer significant benefit to overall Phase C activity.
Supporting Development (SD)	High	-	If SD is Mandatory (Priority 1).
		-	If start is after Phase C PDR, but prior to Phase C CDR.
		-	If SD task appears to offer limited benefit to overall Phase C activity.
	Nominal	-	If SD is Desirable (Priority 2).
		-	If start is prior to Phase C PDR and completion is scheduled prior to Phase C CDR.
		-	If SD task appears to offer moderate benefit to overall Phase C activity.
	Low	-	If SD is Potential (Priority 3).
		-	If both start and completion are scheduled prior to Phase C PDR.
		-	If SD task appears to offer significant benefit to overall Phase C activity.

8.3.2 Program Critical

SRT tasks are considered Program Critical if they have been identified as follows:

1. SRT Category   -   Research
    Schedule Risk   -   High
    Priority   -   1 - Mandatory

2. SRT Category   -   Advanced Technology
    Schedule Risk   -   High
    Priority   -   1 - Mandatory

Other SRT tasks which have lesser classifications are not considered to be Program Critical.

8.4 OVERALL SYSTEM RANKING

The objective of the importance ranking is to interrelate the candidate SRT tasks according to their relative importance to the Cloud Physics Laboratory The following numerical assignments were made to establish a consistent basis for quantifying the importance of the SRT tasks. The lowest assigned number equates to the highest rank within each of the elements contributing to the total score, and the lowest total score is for the highest rank.

	Rank No.	Element		
1.		SRT Category		
	1	Supporting Development	-	SD
	2	Advanced Development	-	AD
	3	Advanced Technology	-	AT
	4	Research	-	R
2		Schedule Risk		
	1	Low		
	2	Nominal		
	3	High		
3.		Priority		
	1	Mandatory		
	2	Desirable		
	3	Potential		
4		Program Critical		
	1	No		
	2	Yes		
5.		Impact		
	1	Safety / Contamination Requirements / Subsystem Capability		
	2	Reliability / Maintainability / Flexibility		
	3	Mission Experiment Time / Experiment Data Quality / Experiment Data Quantity		
	4	Ground Refurbishment/Maintenance		

8.5 SUPPORTING RESEARCH AND TECHNOLOGY CATEGORIES

8.5.1 Research (R)

Research is the activity directed toward an increase in scientific and engineering knowledge intended to provide high confidence in proposed problem solutions. When the research has programmatic implications, it is applied rather than basic research, and addresses only the Conceptual Phase (Phase A) of Phased Project Planning. To minimize program cost and risk, any items in this category should normally be completed by the time Phase B is initiated.

8.5.2 Advanced Technology (AT)

Advanced Technology is the activity of advancing the state of the art in the field of methods and techniques through the application of science and engineering. Any associated hardware effort does not go beyond that required to demonstrate the validity of the advanced method of technique. The AT category of SRT is concerned primarily with the Conceptual Phase (Phase A) and only has a secondary concern with the Definition Phase (Phase B). The activity should be completed before the start of the Design/Development Phase (Phase C), if program risk and cost are to be minimized.

8.5.3 Advanced Development (AD)

Advanced Development is the activity of developing systems, subsystems, or components which are recognized as having long development times and the development completion is required prior to Phase D - Production approval on the project in which the developments will be utilized. The prime reason for accomplishing this category of SRT is to strengthen the performance requirement portion of the respective specification for each specific hardware item. The technology is present state of the art and the broad feasibility has been proven. There remains the AD task of integrating the specific elements into a workable subsystem/system and demonstrating operational capability. The activity usually starts during the Definition Phase (Phase B), but it may start some months prior to this time and extend into the Design Phase (Phase C).

8.5.4 Supporting Development (SD)

Supporting Development is the activity of developing: (1) backup or alternate systems, subsystems, or components; and (2) fabrication, cost and evaluation techniques. Advances in the state of the art may or may not be incorporated. The products of this activity are hardware or techniques suitable for replacing their primary counterparts in the development program. The SD category of SRT is primarily concerned with the Design Phase (Phase C). Initiation of this activity during Phase C should accelerate the baseline development schedule and reduce program risk.

8.6 SUPPORTING RESEARCH AND TECHNOLOGY - TECHNOLOGY AREAS

8.6.1 Acoustics/Acoustical

This technology area pertaining to acoustic frequency generating equipment. Acoustical drivers, microphone pickup, amplifiers, and phase-lock loop controllers are included in this category.

8.6.2 Fluid Dynamics

This technology area pertains to liquid containment and flow control equipment. Reservoirs, flow tubes, capillary surfaces, and flow restrictors are included in this category.

8.6.3 Electromechanical

This technology area pertains to equipment incorporating both electrical and mechanical design features and their control. It includes a broad spectrum of elements/components and their interaction operation.

8.6.4 Optics/Optical

This technology area pertains to light generation and detection equipment which includes laser sources, high intensity light sources, conventional light sources, optical filters, focusing optics, and their support elements.

8.6.5 Structural/Mechanical

This technology area pertains to structural and mechanical equipment. The chemical analysis, stress characteristics, mechanical design, and manufacturing techniques of equipment are included in this category.

8.6.6 Thermal

This technology area pertains to heat transfer equipment. Heat pipes, thermoelectric modules, heat exchanger manifolds, insulation coolant baths, and coolants are included in this area.

8.7 SUPPORTING RESEARCH AND TECHNOLOGY - ITEMS

The SRT identified for the Cloud Physics Labor . ·ry was evaluated for classification into Research, Advanced Technology, Advanced Development, and Supporting Development categories. The Cloud Physics Laboratory SRT items were found to be in the Advanced Development category.

Detailed data for each SRT item are presented in the following pages. Each item includes (1) a description of the SRT item as conceived and why it is required, (2) a brief discussion of the status of the technology and the effort to be accompli˜hed by the SRT, and (3) the project and specific experiment classes affected. Also included are the benefits to be derived by the SRT, and the time span required for development.

PARTICLE GENERATORS SUBSYSTEM

1. **ITEM:**   PARTICLE INJECTOR AND SIZE CONDITIONER
2. **CATEGORY**   ADVANCED DEVELOPMENT
3. **TECHNOLOGY AREA:**   STRUCTURAL/MECHANICAL/THERMAL
4. **DESCRIPTIVE DATA:**

A. DESCRIPTION

Supercooled water droplets and single ice crystals of precise size and "structure" are required by a portion of the defined experiment program. These droplets and crystals must be grown in a precisely controlled temperature, pressure and relative humidity environment and then propelled to the appropriate position or with an appropriate velocity and direction into the cloud chamber. The envisioned particle injector and size conditioner contains features to accomplish these requirements. The particle injector and size conditioner is a miniature thermal diffusion chamber incorporating the features described for the chamber wall subassembly and the acoustical and/or optical conditioning subassembly. The device would contain appropriate viewports and accommodate installation of a generator to provide the original particle.

B. TECHNOLOGY AVAILABLE

The particle injector and size conditioner is classified as laboratory equipment. Elements of this device are used separately in terrestrial laboratories. The primary objectives of the development effort are (1) to perform analyses to establish device size, environment control range and tolerances, geometric shape, viewport location, generator mounting location, and particle injection velocity range, control and tolerance; (2) analytically evaluate the interface requirements between the device and the cloud chamber; and (3) fabricate and test a preprototype device to provide assurance of concept adequacy and to refine requirements and design features for the equipment.

C. PROJECT AFFECTED

Zero Gravity Atmospheric Cloud Physics Laboratory. The following Experiment Classes are affected:

Classes 2, 3, 4, 5, 6, 7, 8 and 12

D. BENEFITS

The development effort will provide the required analysis, design, and test data necessary for confidence that the particle injector and size conditioner can be developed in accordance with project schedule. Accomplishment will permit conduct of experiments requiring particle "collision" or "dynamic" features. Experiment timeline efficiency necessitates the generation and positioning (including velocity and direction control) of particles to be performed in a predictable manner.

E. SCHEDULE   21 months

EXPERIMENT CHAMBERS AND AEROSOL CONDITIONING SUBSYSTEM

1. ITEM: CHAMBER WALL SUBASSEMBLY
2. CATEGORY: ADVANCED DEVELOPMENT
3. TECHNOLOGY AREA: ST.\UCTURAL/MECHANICAL/THERMAL
4. DESCRIPTIVE DATA:

    A.   DESCRIPTION

        The thermally controlled walls of the cloud chamber must be
accurately maintained, with a very precise uniformity for all
experiments. The chamber wall subassembly to satisfy the
experiment requirements consists of heat pipe cavity wall surfaces,
thermoelectric modules, heat exchanger/manifold, and outer wall
shell. The heat pipe cavity wall surfaces provide the chamber
thermal environment control to $\pm 0.2°C$ with a thermal uniformity
of $\pm 0.02°C$. The thermoelectric modules provide a heat pump
capability and accomplish both heating and cooling of the wall
surfaces. The insulation is utilized to reduce the thermal leakage
from the chambers and to enhance thermal uniformity. The heat
exchanger/manifold provides the coolant distribution between the
thermoelectric modules and the Spacelab coldplate $(10°C)$. The
outer wall shell provides the cloud chamber structural integrity
and protection for chamber wall elements.

    B.   TECHNOLOGY AVAILABLE

        The chamber wall subassembly is classified as laboratory equip-
ment. Operating terrestrial laboratories use water-cooled chamber
walls and the associated large thermal baths. Effort has been
expended on use of thermoelectrics, but without heat pipes, for
chamber wall thermal control. Chamber design development efforts
have been conducted and have established the feasibility of the
heat pipe/thermoelectric module concept for chamber wall sub-
assembly usage. The development requirements of this effort
necessitate analysis, design and test of chamber wall subassembly

elements. Altern te heat pipe surface concepts must be evaluated for thermal control and uniformity. The technique for thermo-electric mounting and mount location on heat pipe surfaces must be evaluated. The selection of material insulation and thickness and the heat exchanger configuration and coolant flow must be established. The integration of adjacent wall surfaces and the thermal control of chamber wall surfaces to the required tolerances must be demonstrated.

C. PROJECT AFFECTED

Zero Gravity Atmospheric Cloud Physics Laboratory. The following Experiment Classes are affected:

Classes 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19 and 20.

D. BENEFITS

This development effort will provide the required analysis, design and test data necessary for confidence that the cloud chambers can be developed in accordance with project schedule. The cloud chamber thermal control is required for all experimentation envisioned. Cloud chamber physical and operational characteristics are predicted on the usage of the heat pipe thermoelectric modules chamber wall concept. Accomplishment will reduce project risk for this equipment and maintain the predicted experiment time-line efficiency.

E. SCHEDULE   18 months

EXPERIMENT CHAMBERS AND AEROSOL CONDITIONING SUBSYSTEM

1. **ITEM:**　　　　　　　　ACOUSTICAL SUBASSEMBLY
2. **CATEGORY:**　　　　　　ADVANCED DEVELOPMENT
3. **TECHNOLOGY AREA:**　　ACOUSTICS/ACOUSTICAL
4. **DESCRIPTIVE DATA:**

A. DESCRIPTION

The acoustical subassembly provides motion and orientation control
of droplets and ice crystals within the cloud chamber, and, in
specific instances exact orientation control of ice crystal. Up to
three axes of acoustical control may be required. The subassembly
will consist of acoustical sources, microphone pickup/amplifiers,
phase-lock loop controller, and power amplifier. The acoustical
sources provide the sound waves utilizing electrical drive. The
microphone pickup/amplifier detects the acoustic wave and
generates a signal to provide feedback to the controller. The
phase-lock loop controller processes the driving frequency inform-
ation to maintain the desired acoustic standing wave pattern. The
power amplifier transforms the control signal to the level appro-
priate for the acoustical drivers.

B. TECHNOLOGY AVAILABLE

The acoustical subassembly is classified as laboratory equipment,
although some components are commercial state of the art. NASA
is presently performing a development effort (Jet Propulsion Labora-
tory) on an acoustical subassembly for the Space Processing Payload.
The progress of this effort will be used as a basis for development of
an acoustical subassembly for the Cloud Physics Laboratory. This
effort is to establish the acoustical level determination and the
required positioning feedback control required. The design aspects
of different cloud chamber geometries and surfaces must be
evaluated to establish acoustic driver design.

C. **PROJECT AFFECTED**

Zero Gravity Atmospheric Cloud Physics Laborato·.   The
following Experiment Classes are affected.

Classes 2, 3, 4, 5, 6, 7, 9, 10, 13, 17, 18 and 20.

D. **BENEFITS**

This development effort will provide the required design and test
data necessary for confidence that the acoustical subassembly can
be developed in accordance with the project schedule. Accomplish-
ment will enhance operation of four cloud chambers and over
50 perc .t of the experiment classes. Experiment timelines
efficiency and observation of large particles over long time periods
a: . dependent on this development.

E. **SCHEDULE**   15 months

EXPERIMENT CHAMBERS AND AEROSOL CONDITIONING SUBSYSTEM

1. ITEM: ELECTRIC FIELD SUBASSEMBLY

2. CATEGORY: ADVANCED DEVELOPMENT

3. TECHNOLOGY AREA: ELECTRONIC/ELECTRICAL

4. DESCRIPTIVE DATA:

A. DESCRIPTION

The electric field subassembly will provide a uniform electric field
in which droplets and ice crystals can be grown and within which
dynamic cloud electrification studies of combinations of particles
can be performed. The subassembly consists of field "plates",
ac field controller, dc field controller, and a power converter.
The field "plate" geometry will be different for each cloud chamber.
These "plates" will be positioned adjacent to the chamber walls and
incorporate the appropriate electrical standoffs required for
electrical isolation in a high humidity environment. The "plates"
furthermore, must permit the free transport of water vapor from
the upper to the lower diffusion cloud chambers' wicking surfaces.
The ac field controller is a programmable unit that provides signal
frequency and amplitude control. The dc field controller is similar
to the ac field controller but provides only voltage amplitude control.
The power controller supplies the appropriate high voltages for the
electric field "plates."

B. TECHNOLOGY AVAILABLE

The electric field subassembly is classified as laboratory equipment.
The basic components of the subassembly are commercial state of the
art. The prime development requirement is to reconfigure the
terrestrial laboratory equipment to manned aerospace configurations
usable for the various cloud chambers. Of particular importance
are the definition of the field "plates" and the electrical isolation of
the subassembly high voltages. Additionally, effort must be
expended in the development of programmable field controllers.

C. PROJECT AFFECTED

Zero Gravity Atmospheric Cloud Physics Laboratory. The following Experiment Classes are affected:

Classes 2, 3, 4, 5, 6, 7, 8, 10, 14, 17, 18, and 20.

D. BENEFITS

The development effort will provide the require analysis, design and test data necessary for confidence that the electric field subassembly can be developed in accordance with project schedule. This subassembly is required for all charge measurement experiments. Accomplishment will reduce project risk for this equipment.

E. SCHEDULE   15 months

EXPERIMENT CHAMBERS AND AEROSOL CONDITIONING SUBSYSTEM

1. **ITEM:**   OPTICAL CONDITIONING SUBASSEMBLY
2. **CATEGORY:**   ADVANCED DEVELOPMENT
3. **TECHNOLOGY AREA:**   OPTICS/OPTICAL
4. **DESCRIPTIVE DATA:**

   ## A. DESCRIPTION

   The optical conditioning subassembly will provide remote heating
   of droplets and ice crystals in a cloud chamber. Additionally,
   this subassembly will be used for positioning of particles by
   impingement of a highly configured light beam of a nonabsorbing
   wavelength. The subassembly consists of a light source with
   appropriate filters, focusing optics, protective housing, and fan.
   The high-intensity light source provides the appropriate wavelength
   for particle remote heating or positioning. The optics will focus
   the light source to image sizes of 1 mm or smaller. The protective
   housing and fan will permit beam positioning and provide the forced
   air cooling of the light source.

   ## B. TECHNOLOGY AVAILABLE

   The optical subassembly is classified as laboratory equipment.
   Optical positioning has been demonstrated in terrestrial laboratories
   for 20-micrometer-diameter particles. A number of radiative
   optical sources are presently available. Specific selection,
   determination of beam and filter requirements, beam aiming and
   control techniques are to be accomplished by this effort. Theory
   and laboratory effort indicate that wavelength, beam shape, and
   beam power can be appropriately selected for the optical sub-
   assembly requirements.

   ## C. PROJECT AFFECTED

   Zero Gravity Atmospheric Cloud Physics Laboratory. The following
   Experiment Classes are affected:

       Classes 3, 5, 7, 8, 10, 12, 17, 18, and 20.

D. BENEFITS

This development effort will provide the required analysis, design, and test data necessary for confidence that the optical subassembly can be developed in accordance with the project schedule. Accomplishment will enhance those equipments requiring individual particle remote heating and/or positioning. Use of the optical subassembly is necessary for efficient experiment timeline operation and to extend observational duration of particles.

E. SCHEDULE   15 months

PARTICLE CHARACTERIZERS AND DETECTORS SUBSYSTEM

1. **ITEM:**   CLOUD OPTICAL CHARACTERIZER
2. **CATEGORY:**   ADVANCED DEVELOPMENT
3. **TECHNOLOGY AREA:**   OPTICAL/ELECTROMECHANICAL
4. **DESCRIPTIVE DATA:**

   A. **DESCRIPTION**

   The cloud optical characterizer is a prime element of the scatter-
   ometer, liquid water content meter, and the droplet size distribution
   meter. Although the cloud optical characterizer is used in different
   operating modes, in each of these devices the basic elements are
   identical. The laser source, the optical detector, the alignment
   mechanism, and the scanning mechanism (used only for the
   scatterometer) are contained in the cloud optical characterizer.
   The laser source emits a continuous beam of coherent light,
   expanded by means of a beam expander, across the sample. The
   optical detector is positioned beyond the sample and detects the
   diffraction pattern which depends only on the dimensions of the
   particles in the sample. Single or multiple detectors are used, with
   and without scanning depending on the desired output data form and
   use.

   B. **TECHNOLOGY AVAILABLE**

   The cloud optical characterizer is classified as laboratory equipment,
   although commercial devices exist for specific uses. The laser
   light source exists and the optical detector technology advances of
   recent years are significant. The development areas for the cloud
   optical characterizer consist of analysis, design, fabrication,
   integration, test and evaluation of the components with consideration
   of its use in the configurations and operating modes required by the
   scatterometer, the liquid water content meter and the droplet size
   distribution meter. Additionally, the characterization of the cloud
   optical characterizer must be accomplished to provide assurance that
   data can be accurately evaluated (calibration against known standards).

C. PROJECT AFFECTED

Zero Gravity Atmospheric Cloud Physics Laboratory. The following Experiment Classes are affected:

1, 2, 3, 5, 7, 8, 9, 11, 12, 13, 14, 15, and 20

D. BENEFITS

This development effort is required to provide the required design and test data necessary for confidence that the cloud optical characterizer can be developed in accordance with the project schedule. Accomplishment will enhance the quality and quantity of experimental data available and permit a high degree of commonality for scatterometer, liquid water content meter, and droplet size distribution meter design.

E. SCHEDULE 15 months

EXPERIMENT CHAMBERS AND AEROSOL CONDITIONING SUBSYSTEM

1. **ITEM:**   WATER WICKING SURFACES
2. **CATEGORY:**   ADVANCED DEVELOPMENT
3. **TECHNOLOGY AREA:**   FLUID DYNAMICS
4. **DESCRIPTIVE DATA:**

A. DESCRIPTION

The water wicking surfaces of the diffusion chambers are fine wire mesh screens or equivalent capillary material surfaces that permit the establishment of the required chamber relative humidity. The surfaces must be maintained at a thickness of less than 0.3 mm. The surfaces are critical to the free transport of water vapor and must be maintained "clean" and free of surface contaminants. Requirements exist for both periodic change of water and the continuous flow of water on these surfaces.

B. TECHNOLOGY AVAILABLE

The water wicking surfaces are classified as laboratory equipment. Terrestrial laboratory surfaces are constructed of felt, paper, or similar materials and are prewetted or utilize gravity for initial saturation. The surfaces use gravity for both addition and removal of water. The surfaces are removed from the chambers for cleaning/replacement or maintenance. The water wicking surface development areas consist of a selection of a material that is self-wetting and the determination of design features that permit the addition, removal, and flow of water on the surfaces in a near-zero-gravity environment. Additional efforts are required to establish the formation of ice on these surfaces and its subsequent melting and removal.

C. PROJECT AFFECTED

Zero Gravity Atmospheric Cloud Physics Laboratory. The following
Experiment Classes are affected:

Classes 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 15, 16, 17,
18, 19, and 20.

D. BENEFITS

This development effort is required to permit efficient experiment
operation. Accomplishment of this development will enhance
diffusion cloud chamber design, permit accomplishment of experi-
mentation in less time and enhance chamber operational
characteristics.

E. SCHEDULE   12 months

EXPERIMENT CHAMBERS AND AEROSOL CONDITIONING SUBSYSTEM

1. ITEM: EARTH SIMULATION MODEL
2. CATEGORY: ADVANCED DEVELOPMENT
3. TECHNOLOGY AREA: STRUCTURAL/MECHANICAL/FLUID
                        DYNAMICS

4. DESCRIPTIVE DATA:

A. DESCRIPTION

The earth simulation model will simulate specific aspects of
planetary and solar convection. The assembly consists of a
differentially heated rotating spherical annulus of dielectric
fluid containing suspended particles to provide a visual tag of fluid
circulation. The inner and outer concentric spheres encapsulating
the dielectric fluid provide simulated radial gravitational gradients
and incorporate features to permit variable rotation rate and
thermal heating. The outer sphere consists of a transparent upper
hemisphere and a metallic lower hemisphere with electrically
conductive inner surfaces. The optical properties of the upper
hemisphere must be of a uniformity required for direct photo-
graphy of the dielectric fluid and suspended particles. The inner
sphere must be electrically and thermally conductive. The dielectric
fluid strength is required to permit upwards of 20 kv/cm electric
field, and the suspended particles must be of several micrometer
for photographic data or submicrometer size for use with a laser
anemometer.

B. TECHNOLOGY AVAILABLE

The earth simulation model is classified as laboratory equipment.
For terrestrial research, a model has been developed and tested.
The experiment utilizing this model has been proposed for space
flight. The effort for design, development, test, and evaluation
of the earth simulation model for space flight has not been performed.
The prime development requirement is to refine the model analysis
to permit selection of materials, surface coatings, dielectric fluid

and particulates. A preprototype model must be fabricated and
evaluated in a terrestrial environment to provide assurance of
concept adequacy and establish requirements for model operation
and control.

C. **PROJECT AFFECTED**

Zero Gravity Atmospheric Cloud Physics Laboratory. The
following Experiment Class is affected:

Class 21

D. **BENEFITS**

This development effort will provide the required analysis, design
and test data necessary for confidence that the earth simulation
model can be developed in accordance with the project schedule.
Accomplishment will reduce project risk for this equipment.

E. **SCHEDULE**   15 months

Section 9
CLOUD LABORATORY SUPPORT OPERATIONS

There are two major factors that become the basic background for this
analysis and description of the Cloud Physics Laboratory (CPL) operation:
(1) the CPL operates as a partial payload of the Spacelab which in turn is
a payload of the Shuttle; and (2) the philosophy of principal investigator
(PI) participation in the CPL. The discussion of these factors will be
further expanded in this section. The first portion describes how a CPL
will be handled during the cycle from flight return to the next flight return.
The last portion defines the roles and operations of the CPL program and
the PI's in planning for and obtaining data from the CPL experiments.

9.1 CPL OPERATIONS
In this section a CPL ground and flight operation schedule with manpower
loading is developed. The following significant conclusions and require-
ments can be drawn from the CPL operations schedule and the supporting
analysis:

A.   The tasks associated with a CPL console can be expected to be
     accomplished within a 6-month turnaround with no more than
     5 percent overtime.

B.   By having one ground crew servicing two CPL's, the peaks and
     valleys in the manpower requirements for a single CPL will
     complement the second and will probably allow for efficient use
     of the manpower required. In other words, CPL ground service
     crew will be busy servicing the second CPL when the Spacelab/
     Shuttle operations would preclude activities on the first laboratory.
     Further analysis will be required to verify and determine the
     extent of project economies.

C. The PI/NASA interface dates can be defined as follows:
   1.   The PI will receive hard data 2 to 3 weeks after recovery.
   2.   CPL mission configuration definition is required 5 months
        before launch.
D. The following five pieces of ground support equipment are unique
    to and required for the CPL ground and support operations:
   1.   Gas service cart
   2.   Water service cart
   3.   Cleaning kit
   4.   Handling fixture No. 1. This fixture supports and protects
        the CPL and secondary Spacelab structure in test and
        transportation.
   5.   Handling fixture No. 2. This handling fixture is used to
        support the various components of the CPL during the mainten-
        ance and refurbishment (M&R) operations.
E. The Spacelab simulator for experiments is supplied to the CPL pro-
    ject for use at both the user (contractor) and integration sites.
    (see Figure 9-1)

9.1.1 CPL Ground Operations

Because the CPL is only a partial payload on the Spacelab, which in itself
is a payload of the Orbiter, the ground operations scenario for the CPL is
depicted as one portion of the total overall Shuttle and Spacelab operations
planning. In Figure 9-1, the Shuttle is shown returning to the Orbiter
Checkout Facility (OCF) after landing from a flight. In the OCF, the
Spacelab is extracted and transported to the Manned Spaceflight Operations
Building (MSOB). It is in this building that the CPL and secondary structure
are extracted from the Spacelab. The two-way circular path shown between
the MSOB, user site, and integration site is to show all potential hardware
transportation links. The CPL hardware will originate at the user site, be
sent to the integration site for checkout, and from the integration site to the
MSOB for flight. Upon return, the hardware may be sent to either the user
site or the integration site, depending upon future decisions as to where
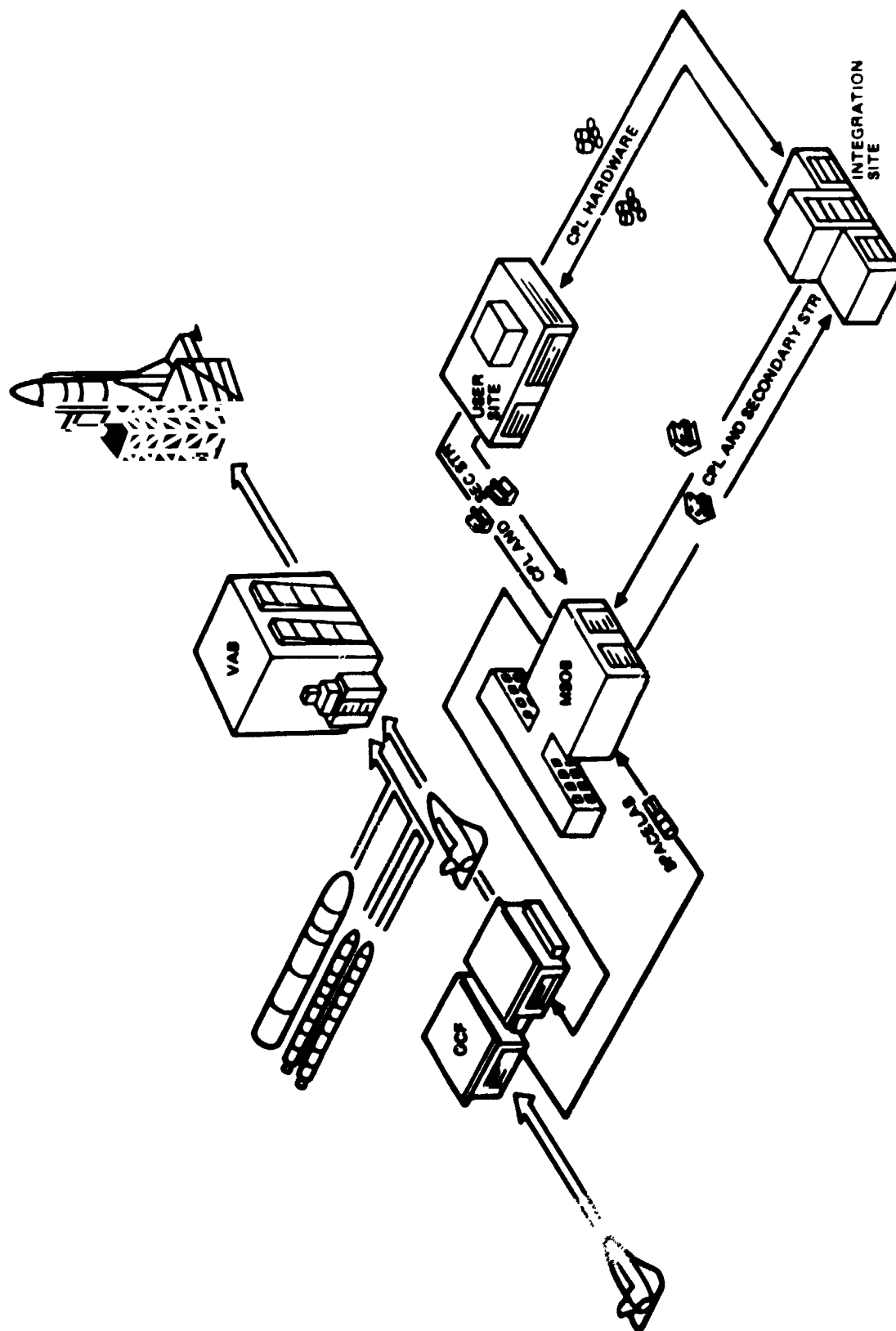
Figure 3-1. CPL Ground Operations Scenario

the maintenance and refurbishment is to be performed. Figure 9.2 shows the sequence of sites in the CPL ground operations scenario and lists the expected operations at that site. The listing of the tasks was not meant to be in order: it defines all the operations performed at the site at that time. It can be seen, for example, that between the integration and user site there was no decision made as to where the M&R would be performed; the M&R could be performed at either site.

9.1.2 Functional Flow Diagrams

All operations, both ground and flight, are divided into five flow diagrams that are shown in Figures 9-3 to 9-7. The KSC postlanding recovery flow is shown in Figure 9-3. On Figure 9-4 in addition to the maintenance and refurbishment flow, there is a task assignment sheet that is representative of these prepared for each block of all the functional flow block diagrams. Figure 9-5 is the integration check out flow; Figure 9-6 is prelaunch and launch checkout flow and Figure 9-7 is the mission operations flow. The functional flow diagrams define task and task phasing; the task assignment sheets define the manpower, skill level, and equipment required for each block in the functional flow diagram.

9.1.3 CPL Operational Schedule

Figure 9-8 defines the CPL operational timeline and the manpower required. This turnaround schedule provides insight into the CPL operations scenario in terms of manpower, phasing, and level in program operations. No attempt was made to smooth manpower levels. From the manpower levels at the bottom of the figure, it can be seen that the average level of five workers on days worked results in a long gap and an average level of less than four people. The box on the upper right side of Figure 9-8 sums man-days worked by skill and shows a 60 percent M&R crew efficiency. Shuttle and Spacelab operations preclude CPL operations for over 28 percent of the operational turnaround. The use of one crew to service two CPL's on 3 months centers will allow for significant increase in crew efficiency and facilitate smoothing of manpower variations.
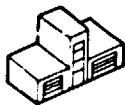
INTEGRATION SITE

CPL CHECKOUT AND INTEGRATION WITH SPACELAB SECONDARY STRUCTURE	CPL PRELAUNCH CHECKOUT/ SERVICING	CPL OPERATIONS DURING SPACELAB TRANSPORT	CPL OPERATIONS AFTER SPACELAB/ ORBITER INTEGRATION

CPL CHECKOUT AND INTEGRATION WITH SPACELAB SECONDARY STRUCTURE

- RECEIVE AND INSPECT CPL AT INTEGRATION SITE
- TRANSPORT CPL TO CHECKOUT AREA
- PREPARE CPL FOR CHECKOUT
- SERVICE CPL FOR CHECKOUT OPERATIONS
  - GAS
  - WATER
  - MAGNETIC TAPE
- CONNECT CPL TO SPACELAB SIMULATOR
- VERIFY CPL CALIBRATION
- PERFORM CPL ACTIVATION AND VERIFY SYSTEMS OPERATION
- VERIFY ON-ORBIT CONFIGURATIONS
- PERFORM CPL DEACTIVATION SEQUENCE AND VERIFY SYSTEMS OPERATION
- EVALUATE SYSTEMS CHECKOUT DATA
- CERTIFY CPL FOR FLIGHT
- DISCONNECT CPL FROM SPACELAB SIMULATOR
- DESERVICE CPL
  - GAS
  - WATER
  - MAGNETIC TAPE
- CONFIGURE CPL FOR LAUNCH
- INSTALL CPL ON/IN SPACELAB SECONDARY STRUCTURE AND VERIFY
- PREPARE FOR TRANSPORT TO LAUNCH SITE
- TRANSPORT TO LAUNCH SITE
- PRESSURIZE CPL GAS SYSTEMS TO FLIGHT LEVELS AND LEAK CHECK
- FILL CPL WATER SYSTEM AND LEAK CHECK
- VERIFY CLEANLINESS
- PURIFY CPL WATER
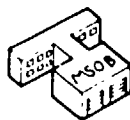
CPL PRELAUNCH CHECKOUT/SERVICING

- RECEIVE SECONDARY STRUCTURE AT LAUNCH SITE
- TRANSPORT TO MSOB
- CPL RECEIVING AND INSPECTION AT MSOB
- PREPARE CPL FOR PRELAUNCH CHECKOUT AND SERVICING
- CONNECT SERVICE CARTS TO CPL
- PRESSURIZE CPL GAS SYSTEMS TO FLIGHT LEVELS AND LEAK CHECK
- PURIFY CPL WATER
- FILL CPL WATER SYSTEM TO FLIGHT LEVELS AND LEAK CHECK
- INTEGRATION PREPARATIONS
- INTEGRATE SECONDARY STRUCTURE MOUNTED CPL WITH SPACELAB PRIMARY STRUCTURE UTILIZING HANDLING FIXTURE
- VERIFY MECHANICAL I/F
- VERIFY ELECTRICAL I/F
- VERIFY DATA I/F
- REMOVE HANDLING FIXTURE
- CONNECT SHUTTLE INTEGRATION DEVICE
- POWER-UP CPL AND PERFORM ABBREVIATED FUNCTIONAL TEST
- VERIFY CPL/SPACELAB/ORBITER POWER AND DATA I/F
- EVALUATE FUNCTIONAL TEST RESULTS
- REMOVE SHUTTLE INTEGRATION DEVICE
- RESERVICE CONSUMABLES
- CONFIGURE CPL FOR LAUNCH
- INSTALL FLIGHT FILM AND TAPES
- VERIFY CPL READY FOR CLOSEOUT
- CERTIFY CPL READY FOR FLIGHT
- SPACELAB SEGMENTS MATING AND SUBSEQUENT SPACELAB OPERATIONS
- DELETED
- VERIFY CLEANLINESS
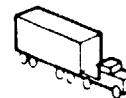
CPL OPERATIONS DURING SPACELAB TRANSPORT

- NO CPL OPERATIONS IDENTIFIED
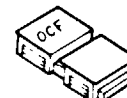
CPL OPERATIONS AFTER SPACELAB/ORBITER INTEGRATION

- NO CPL OPERATIONS IDENTIFIED

				CLOUD PHYSICS LABORATORY OPERATIONS	

CPL OPERATIONS AFTER SPACELAB/ORBITER INTEGRATION

- NO CPL OPERATIONS IDENTIFIED

CPL OPERATIONS DURING SHUTTLE STACKING

- NO CPL OPERATIONS IDENTIFIED

CPL OPERATIONS AT LAUNCH PAD

- VERIFY CPL GAS PRESSURE
- VERIFY CPL WATER LEVEL

CPL ON-ORBIT OPERATIONS

- ENTER SPACELAB
- SPACELAB SYSTEMS ACTIVATED AND VERIFIED
- VISUALLY INSPECT CPL
- POWER UP CPL
- VERIFY ORBITER/SPACELAB/CPL DATA INTERFACE
- ACTIVATE CPL TO OPERATING
- CONFIGURATION
- CPL CHECKOUT
- CPL OPERATOR/ECC DEBRIEFING
- PERFORM CPL EXPERIMENT FLIGHT PLAN
    - EXPERIMENT NO. 1
    - ECC DEBRIEFING
    - RECONFIGURE CPL
    - EXPERIMENT NO. 2
    - ETC
- MONITOR CPL SYSTEM PERFORMANCE FOR ANOMALIES
- MCC DEBRIEFING
- DEACTIVATE CPL
- CONFIGURE CPL FOR RETURN
- STOW FILM/TAPE/SAMPLES
- VENT CONSUMABLES OVERBOARD PRIOR TO SPACELAB CLOSEOUT
- LEAVE SPACELAB
- COMMUNICATIONS NETWORK UTILIZATION/PLANNING
- DATA MANAGEMENT/PLANNING
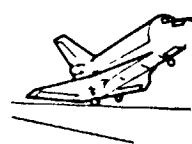
CPL OPERATIONS DURING RETURN

- NO CPL OPERAT. IDENTIFIED

GLOSSARY	
CPL	CLOUD
CIF	CONT.
ECC	EXPER.
MSOB	MANNI
OCF	ORBIT
VAB	VERT.

INTEGRATION SITE

CPL OPERATIONS DURING RETURN	CPL OPERATIONS DURING SPACELAB/ORBITER DEMATE	CPL OPERATIONS DURING SPACELAB DEMATE	CPL MAINTENANCE AND REFURBISH OPERATIONS
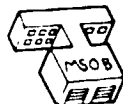
- NO CPL OPERATIONS IDENTIFIED

- NO CPL OPERATIONS IDENTIFIED

- SPACELAB ELEMENTS DEMATE
- VISUAL INSPECTION OF CPL
- CPL MOUNTED SECONDARY STRUCTURE REMOVED FROM SPACELAB PRIMARY STRUCTURE
  - DISCONNECT MECHANICAL I/F
  - DISCONNECT ELECTRICAL I/F
- DESERVICE REMAINING CONSUMABLES IF REQUIRED
- RECOVER EXPERIMENT DATA
- CPL PREPARES FOR SHIPMENT TO CIF OR USER SITE
- SHIP CPL TO CIF OR USER SITE
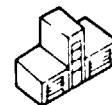
- RECEIVE CPL MOUNTED* SECONDARY STRUCTURE
- TRANSPORT TO M&R* AREA
- UPDATE M&R SCHEDULES*
- RECEIVING AND INSPECTION*
- CONNECT CPL TO* SIMULATOR
- VERIFY OPERATIONAL STATUS/* IN-FLIGHT ANOMALIES
- DISCONNECT CPL FROM* SIMULATOR
- REMOVE CPL EQUIPMENT FROM SECONDARY STRUCTURE
- PERFORM SCHEDULED MAINTENANCE*
- PERFORM SCHEDULED MAINTENANCE*
- CLEAN CPL EQUIPMENT TO* CLASS 10000 TO 100000
- CONFIGURE CPL FOR NEXT MISSION*

ICE

- P.
  T
- SI

GLOSSARY	
CPL	CLOUD PHYSICS LABORATORY
CIF	CONTROL INTEGRATION FACILITY
ECC	EXPERIMENT CONTROL CENTER
MSOB	MANNED SPACE FLIGHT OPERATIONS BUILDING
OCF	ORBITER CHECKOUT FACILITY
VAB	VERTICAL ASSEMBLY BUILDING

CPL FUNCTIONS REQUIRING MAINTENANCE

- THERMAL CONTROL AND MEASUREMENT
- PRESSURE CONTROL AND MEASUREMENT
- DEW POINT AND LIQUID WATER CONTENT CONTROL AND MEASUREMENT
- GAS STORAGE AND FLOW CONTROL
- ELECTRIC FIELD ENVIRONMENT
- ACOUSTIC
- OPTICAL
- LIQUID DROP GENERATOR
- ICE PARTICLE GENERATOR
- OPTICAL AND IMAGING DEVICES
- AEROSOL GENERATORS
- DATA MANAGEMENT AND INTERFACE ELECTRONICS
- PARTICLE COUNTERS
- EXPERIMENT CHAMBERS
- POWER CONTROL AND DISTRIBUTION
- CONSOLE

SITE

USER SITE

CPL
MAINTENANCE
AND REFURBISH
OPERATIONS

ANCE
RBISH
NS

NTED*
CTURE
MR*

EDULES*
NSPECTION*

INAL STATUS/*
ALIES
FROM*

IPMENT
STRUCTURE
ULED MAINTENANCE*
ILED MAINTENANCE*
MENT TO*
00000
FOR NEXT MISSION*

- PREPARES FOR SHIPMENT TO CIF
- SHIP CPL TO CIF

NOTE: *THESE FUNCTIONS MAY BE
PERFORMED AT USER SITE

Figure 9-2. CPL Ground Operations Scenario

FOLDOUT FRAME

4
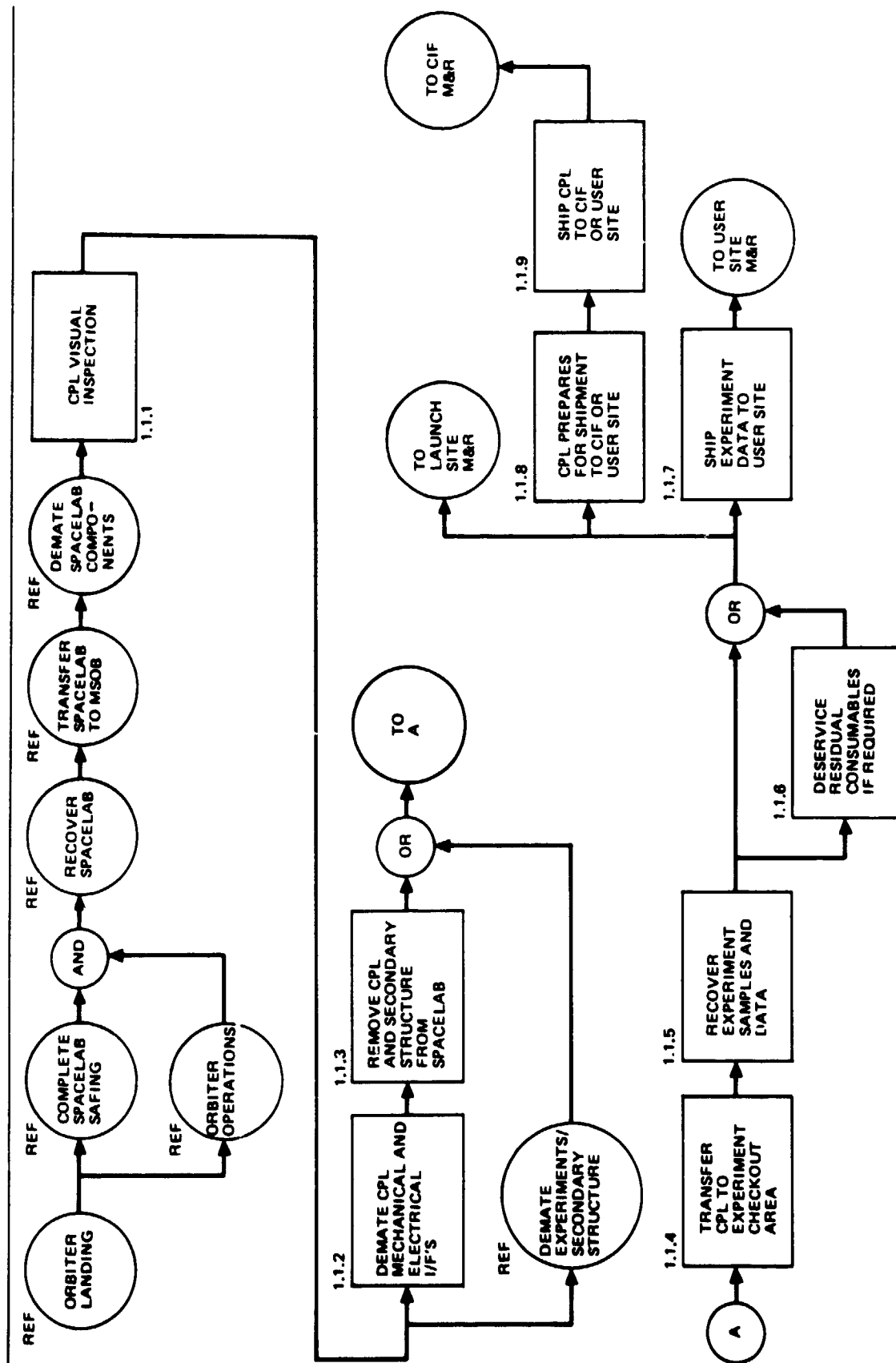
Figure 9-3. Postlanding Recovery Flow

PRECEDING PAGE BLANK NOT FILMED

2.1.1
RECEIVE CPL AT CIF

2.1.2
RECEIVE CPL AT USER SITE

2.1.3
TRANSFER CPL TO LAUNCH SITE M&R AREA

CPL FROM POSTLANDING

CPL FROM STORAGE

OR

OR

2.1.4
TRANSFER CPL TO M&R AREA

OR

2.1.5
PREPARE FOR CHECKOUT AND INSPECTION

2.1.6
PERFORM POST-FLIGHT RECEIVE AN INSPECTION

2.1.10
PREPARE PRELIMINARY M&R SCHEDULE

2.1.11
ANALYZE T/M DATA FOR UNSCHEDULE M&R

2.1.13
PERFORM STRUCTURAL M&R

2.1.14
PERFORM MECHANICAL M&R

2.1.15
PERFORM AVIONICS M&R

A

OR

2.1.16
PERFORM POST M&R VERIFICATION

B

NO M&R REQUIRED

OR

2.1.17
CONFIGURE CPL FOR NEXT MISSION

2.1.18
VERIFY CPL CLEANLIN

2.1.19
VERIFY SECONDARY STRUCTURE CLEANLINES

FAILURE DETECTED

2.1.7

PERFORM
POSTFLIGHT
CHECKOUT

2.1.6

PERFORM
POST-FLIGHT
RECEIVE AND
INSPECTION

2.1.8

PERFORM
POST STORAGE
CHECKOUT

OR

AND

2.1.9

REMOVE
CPL FROM
SECONDARY
STRUCTURE

TO
B

TO
A

2.1.11

ANALYZE T/M
DATA FOR
UNSCHEDULED
M&R

2.1.12

UPDATE
M&R
SCHEDULE

TASK TITLE:

TASK OBJECTIVE:

TASK PURPOSE:

TASK LOCATION:

TASK EQUIPMENT:

MANPOWER REQUIR

PERSONNEL

MECH TECH

AVONIC TECH

ENGINEERIN(
QUALITY CON'

SAFETY

2.1.18

VERIFY
CPL
CLEANLINESS

AND

2.1.20

MATE CPL
TO SECONDARY
STRUCTURE AS
REQUIRED

2.1.21

PREPARE
FOR TRANSPORT
TO INTEGRATION
CHECKOUT

2.1.22

TRANSFER TO
CIF OR LAUNCH
SITE INTEGRATION
CHECKOUT

2.1.19

VERIFY
SECONDARY
STRUCTURE
CLEANLINESS

FOLDOUT FRAME

TO
B

TO
A

TASK DESCRIPTION SHEET

TASK TITLE: (2.1.8) PERFORM POST STORAGE CHECKOUT

TASK OBJECTIVE: DETERMINE CPL STATUS PRIOR TO MAINTENANCE AND REPAIR

TASK PURPOSE: TO INSPECT AND OPERATE CPL TO DETERMINE EXACT STATUS

TASK LOCATION: CIF OR USER'S SITE OR KSC MAINTENANCE AND REPAIR AREA

TASK EQUIPMENT: SPACELAB SIMULATOR, HANDLING FIXTURE, GAS SERVICE
CART, WATER SERVICE CART

MANPOWER REQUIREMENTS:

PERSONNEL	TOTAL TASK TIME:	16 HOURS
MECH TECH	2	
AVONIC TECH	2	
ENGINEERING	1	
QUALITY CONTROL	2	
SAFETY		

CH
ATION

Figure 9-4. Maintenance and Refurbishment Flow

FOLDOUT FRAME
3

```
                    3.1.1              3.1.2              3.1.3              3.1.4
  ┌────────┐    ┌──────────────┐  ┌──────────────┐  ┌──────────────┐  ┌──────────────┐
 │   CPL    │   │ RECEIVE AND  │  │ TRANSPORT    │  │              │  │ CONNECT CPL  │
 │  FROM    │──▶│ INSPECT CPL  │─▶│ TO INTEGRATION│─▶│ PRE-INTEGRATION│─▶│ GAS SERVICE  │──▶
 │  M&R     │   │ AT CIF OR    │  │ AND CHECKOUT │  │ CHECKOUT     │  │ CART         │
  └────────┘    │ LAUNCH SITE  │  │ AREA         │  │ PREPARATIONS │  └──────────────┘
                └──────────────┘  └──────────────┘  └──────────────┘

                                                                        3.1.5
                                                                   ┌──────────────┐
                                                                   │ PURIFY CPL   │
                                                                   │ SERVICE      │──
                                                                   │ WATER        │
                                                                   └──────────────┘

           3.1.9              3.1.10             3.1.11             3.1.12             3.1.13
       ┌──────────────┐  ┌──────────────┐  ┌──────────────┐  ┌──────────────┐  ┌──────────────┐
  (A)─▶│ FILL CPL     │─▶│ PRESSURIZE   │─▶│ REMOVE CPL   │─▶│ PREPARES     │─▶│ CONNEC.      │
       │ WATER SYSTEM │  │ CPL WATER    │  │ SERVICE      │  │ FOR SUBSYSTEM│  │ CPL TO       │
       │ TO FLIGHT    │  │ SYSTEM AND   │  │ CARTS        │  │ INTEGRATION  │  │ SPACEL       │
       │ CAPACITY     │  │ LEAK CHECK   │  │              │  │ CHECKOUT     │  │ SIMULAT      │
       └──────────────┘  └──────────────┘  └──────────────┘  └──────────────┘  └──────────────┘

           3.1.17             3.1.18             3.1.19             3.1.20             3.1.21
       ┌──────────────┐  ┌──────────────┐  ┌──────────────┐  ┌──────────────┐  ┌──────────────┐
  (B)─▶│ PRESSURE     │─▶│ GAS FLOW     │─▶│ THERMAL      │─▶│ OPTICAL      │─▶│ AEROSOL      │
       │ CONTROL      │  │ CONTROL      │  │ CONTROL      │  │ SUBSYSTEM    │  │ GENERATI     │
       │ FUNCTIONAL   │  │ FUNCTIONAL   │  │ FUNCTIONAL   │  │ FUNCTIONAL   │  │ FUNCTION     │
       │ VERIFICATION │  │ VERIFICATION │  │ VERIFICATION │  │ VERIFICATION │  │ VERIFICA     │
       │ TEST         │  │ TEST         │  │ TEST         │  │ TEST         │  │ TEST         │
       └──────────────┘  └──────────────┘  └──────────────┘  └──────────────┘  └──────────────┘

           3.1.25             3.1.26             3.1.27             3.1.28             3.1.29
       ┌──────────────┐  ┌──────────────┐  ┌──────────────┐  ┌──────────────┐  ┌──────────────┐
  (C)─▶│ PARTICLE     │─▶│ ACOUSTIC     │─▶│ PERFORM      │─▶│ PERFORM      │─▶│ DISCONN      │
       │ COUNTER      │  │ SUBSYSTEM    │  │ CPL ON-ORBIT │  │ CPL ON-ORBIT │  │ SPACEL       │
       │ FUNCTIONAL   │  │ FUNCTIONAL   │  │ ACTIVATION   │  │ DEACTIVATION │  │ SIMULAT      │
       │ VERIFICATION │  │ VERIFICATION │  │ SEQUENCE     │  │ SEQUENCE     │  │              │
       │ TEST         │  │ TEST         │  │              │  │              │  │              │
       └──────────────┘  └──────────────┘  └──────────────┘  └──────────────┘  └──────────────┘

           3.1.33             3.1.34                        3.1.36                      3.1.37
       ┌──────────────┐  ┌──────────────┐           ┌──────────────┐             ┌──────────────┐
  (D)─▶│ DESERVICE    │─▶│ REMOVE       │──────────▶│ CLEAN AND    │──▶(AND)──▶  │ CONFIGURE    │
       │ CPL GAS      │  │ SERVICE      │           │ VERIFY CPL   │     │       │ CPL FOR      │
       │ SYSTEMS      │  │ CARTS        │           │ EQUIPMENT    │     │       │ LAUNCH       │
       └──────────────┘  └──────────────┘           └──────────────┘     │       └──────────────┘
                                                                          │
           3.1.41                                      3.1.38             │
       ┌──────────────┐      ┌──────────┐          ┌──────────────┐      │
  (E)─▶│ TRANSPORT    │─────▶│   TO     │          │ EVALUATE     │──────┘
       │ TO LAUNCH    │      │ PRELAUNCH│          │ CPL CHECKOUT │
       │ SITE         │      │ CHECKOUT │          │ DATA         │
       └──────────────┘      └──────────┘          └──────────────┘
```

Figure 9-5. Integration Checkout Flow

4.1.1 RECEIVE CPL AND SECONDARY STRUCTURE AT LAUNCH SITE

4.1.2 TRANSFER CPL TO MSOB

4.1.3 CPL RECEIVING AND INSPECTION

4.1.4 PREPARES FOR CPL CHECKOUT AND SERVICING

FROM CIF INTEGRATION CHECKOUT

4.1.9 CONNECT CPL WATER SERVICE CART

4.1.10 FILL CPL WATER SYSTEM TO FLIGHT CAPACITY

4.1.11 PRESSURIZE CPL WATER SYSTEM AND LEAK CHECK

4.1.12 REMOVE CPL SERVICE CARTS

4.1.13 PREPARES CPL/SL INTEGRATI

4.1.17 VERIFY C&W I/F

4.1.18 PERFORM ABBREVIATED FUNCTIONAL TEST

4.1.20 CERTIFY CPL FOR FLIGHT

4.1.20.a RESERVICE CONSUMABLES IF REQUIRED

4.1.23 VERIFY CPL READY FOR CLOSEOUT

REF SPACELAB SERVICING

REF INSTALL TRANSFER TUNNEL

REF PRESSURE LEAK TEST

REF SPACELAB TRANSFER TO OCF

REF SPACELAB CLOSEOUT

REF SHUTTLE OPERATIONS

REF SPACELAB SERVICING

REF SHUTTLE COUNTDOWN

REF SHUTTLE LAUNCH

4.1.24 VERIFY CPL CONSUMABLES AND C&W

FOLDOUT FRAME

Figure 9-6. Prelaunch and Launch Checkout Flow

FOLDOUT FRAME

Figure 9-7. 5.0 Mission Operations

9-11

ORBITER OPERATIONS 10 REF
COMPLETE SPACELAB SAFING (10 REF)
RECOVER SPACELAB 5 REF
TRANSFER SPACELAB TO MSOB (1 REF)
ORBITER CHECKOUT FACILITY 35 HRS
DEMATE SPACELAB COMPONENTS 16 REF
CPL VISUAL INSPECTION (4)
DEMATE CPL MECH AND ELECT I/F (8)
REMOVE CPL FROM SPACELAB (8)
DEMATE EXPERIMENTS SECONDARY STRUCTURE (25 REF)
TRANSFER CPL TO EXP CHECKOUT AREA (4)
RECOVER EXPERIMENT SAMPLES AND DATA (4)
DESERVICE RESIDUAL CONSUMABLES (4)
MSOB 88 HRS
SHIP EXPERIMENT DATA TO USER SITE (16)
CPL PREPS FOR SHIPMENT TO CIF OR USER SITE (8)
SHIP CPL TO CIF OR USER SITE (16)
RECEIVE CPL (4)
TRANSFER CPL TO MAINT AND REPAIR AREA (4)
PREPARE FOR CHECKOUT AND INSPECTION (4)
PERFORM POST FLIGHT INSPECTION (8)
PERFORM POST FLIGHT CHECKOUT (24)
REMOVE CPL SECONDARY STRUCTURE (16)
UPDATE M&R SCHEDULE
PERFORM STRUCTURAL M&R (24)
ANALYZE T M DATA FOR UNSCHEDULED M&R
PERFORM MECHANICAL M&R (40)
PREPARE PRELIMINARY M&R SCHEDULE
PERFORM AVIONICS M&R (40)
PERFORM POST M&R VERIF (16)
CONFIGURE CPL FOR NEXT MISSION (16)
VERIFY CPL CLEANLINESS (8)
VERIFY SECONDARY STRUCTURE CLEANLINESS (8)
MATE CPL TO SECONDARY STRUCTURE AS REQD (16)
PREPS FOR TRANSPORT TO INTEGRATION CHECKOUT (8)
TRANSFER CPL TO CIF CHECKOUT FACILITY (4)
TRANSFER TO LAUNCH SITE C/O FACILITY (16) REF
RECEIVE AND INSPECT CPL AT C/O FACILITY (8)
PRE INTEG C/O PREPS (8)
CONNECT CPL TO GAS SERVICE CART (4)
PRESSURIZE CPL AND LEAK CHECK (8)
VENT CPL GAS SYSTEMS TO AMBIENT (2)
PURIFY CPL SERVICE CART WATER (8)
CONNECT WATER SERVICE CART TO CPL (4)
FILL CPL WATER SYSTEM (8)
CENTRAL INTEGRATION FACILITY OR USER SITE 571 HRS
PRESSURIZE AND LEAK CHECK CPL WATER SYSTEM (8)
REMOVE CPL SERVICE CARTS (4)
PREPS FOR SYSTEM INTEG C/O (4)
CONNECT CPL TO SPACELAB SIMULATOR (8)
VERIFY MECH/ELEC/DATA I/F (16)
POWER DISTRIBUTION AND CONTROL FUNCT VERIF TEST (16)
DATA MANAGEMENT FUNCT VERIF TEST (16)
PRESSURE CONTROL FUNCT VERIF TEST (16)
GAS FLOW FUNCT VERIF TEST (16)
THERMAL CONTROL FUNCT VERIF TEST (24)
OPTICAL EQUIPMENT FUNCT VERIF TEST (16)
NUCLEI GENERATORS FUNCT VERIF TEST (16)
LIQUID DROP GENERATOR FUNCT VERIF TEST (16)
ICE PARTICLE GENERATOR FUNCT VERIF TEST (16)
IMAGING DEVICES FUNCT VERIF TEST (16)
MISC EQUIPMENT FUNCT VERIF TEST (8)
CLOUD CHAMBER FUNCT VERIF TEST (16)
ON ORBIT ACTIVATION SEQUENCE (16 ALLOCATION)
ON ORBIT DEACTIVATION SEQUENCE VERIF (8 ALLOCATION)
DISCONNECT SPACELAB SIMULATOR (8)
CONNECT WATER SERVICE CART (4)
EVALUATE CPL C/O DATA
DESERVICE CPL WATER SYSTEM (8)
CONNECT GAS SERVICE CART (4)
DESERVICE CPL GAS SYSTEM (4)
REMOVE SERVICE CARTS (4)
CLEAN AND VERIFY CPL EQUIPMENT (16)
MATE CPL WITH SECONDARY STRUCTURE
CONFIGURE CPL FOR LAUNCH (8)
CERTIFY CPL READY FOR LAUNCH
PREPS FOR TRANSPORT TO
TRANSPORT CPL TO LAUNCH

CPL ARRIVAL AT LAUNCH
RECEIVE CPL AT LAUNCH
TRANSPORT TO M
CPL INSPECTION
PREPS FOR C/O
CONNECT GAS
PRESSURIZE
VENT CPL GAS
PURIFY CPL
CONNECT
FILL CPL

WORKING TIME (HOURS)
WORKING TIME (DAYS)

Figure 9-8. Cloud Physics Laboratory Ground and Flight Operations

9.2 EXPERIMENT FLIGHT SUPPORT ANALYSIS

The following are the significant operations conclusions and requirements based on the experiment flight support operations analysis:

A. A CPL experiment control center (ECC) is required to perform the following functions:

    1. Coordinate PI flight plans into a mission flight plan and develop required software.

    2. Train the astronauts

    3. Obtain ground baseline experiment data

    4. Support the MCC for problems in real time concerning the CPL in orbit.

B. There is a need for two simulators at the ECC.

C. The schedule allows the Project Verification Model (PVM) to be available after its use in interface checkout with the Spacelab to be the first simulator at the ECC.

D. The second simulator can be produced mainly from qualification hardware components allowing program economies and still be schedule compatible.

E. The PVM can be used for the first CPL PI's during their experiment plan development.

F. The PI activity schedule starts 24 months before flight when the call for experiment occurs:

    1. By 18 months before flight, the preliminary experiment plan must be submitted.

    2. Eleven months before flight, a 4-month funded effort is completed resulting in a final experiment plan. This 11-month time appears to be a practical minimum.

    3. Six months before flight, the final flight plan must be submitted to the ECC.

    4. For 4 months before flight, the PI assists in astronaut training and obtains baseline data from operation of the ECC simulator.

    5. During flight, the PI is available for consultation as required.

    6. The PI supports the flight crew debriefing and prepares his final report by 6 months after the flight.

9.2.1 PI Role in Experiment Support

The approach to the assignment of roles and responsibilities and the definition of PI participation is based on the following assumptions;

    A.   NASA has the experience in operating experimental equipment in orbit.

    B.   NASA, by means of a CPL project, is able to provide a facility 'hat can significantly increase the level of knowledge in cloud physics.

    C.   Other agencies and people not only retain the research responsibility but define the experiments to be performed.

    D.   The CPL project operations must be organized recognizing and using the roles, responsibilities, and strengths of all concerned.

    E.   Cloud physics research responsibility will remain in the domain of those agencies and organizations presently involved in such efforts.

9.2.2 Typical Flight Support Schedules

The starting point for the development of these schedules is the 6-month CPL turnaround as defined in Subsection 9.1.3. Essentially, the configuration for a flight must be fed into the maintenance and repair activities 5 months before launch of the orbiter containing the Spacelab. Based on this information, the typical experiment flight support schedule (Figure 9-9), was developed. The resulting flow of tasks is as follows: The call for experiments occurs 2 years before the intended flight of the CPL. A preliminary NASA evaluation and selection takes 2 months and selects potential principal investigators (PI) for funded definition of an experiment plan. The PI's then have 4 months to become familiar with the CPL operations and submit an experiment plan 11 months before flight. The final NASA selection for flight takes 3 months. The CPL contractor then has 3 months as lead time to be ready to configure the CPL for flight.

During the final NASA review, the PI starts to prepare his experiment plan because, after final review, he has only 60 days to submit the plan to the CPL experiment control center (ECC) for coordination of a flight plan including all PI inputs. There are then 60 days for the PI's and CPL ECC to coordinate the final flight plan and be ready to train the astronauts.
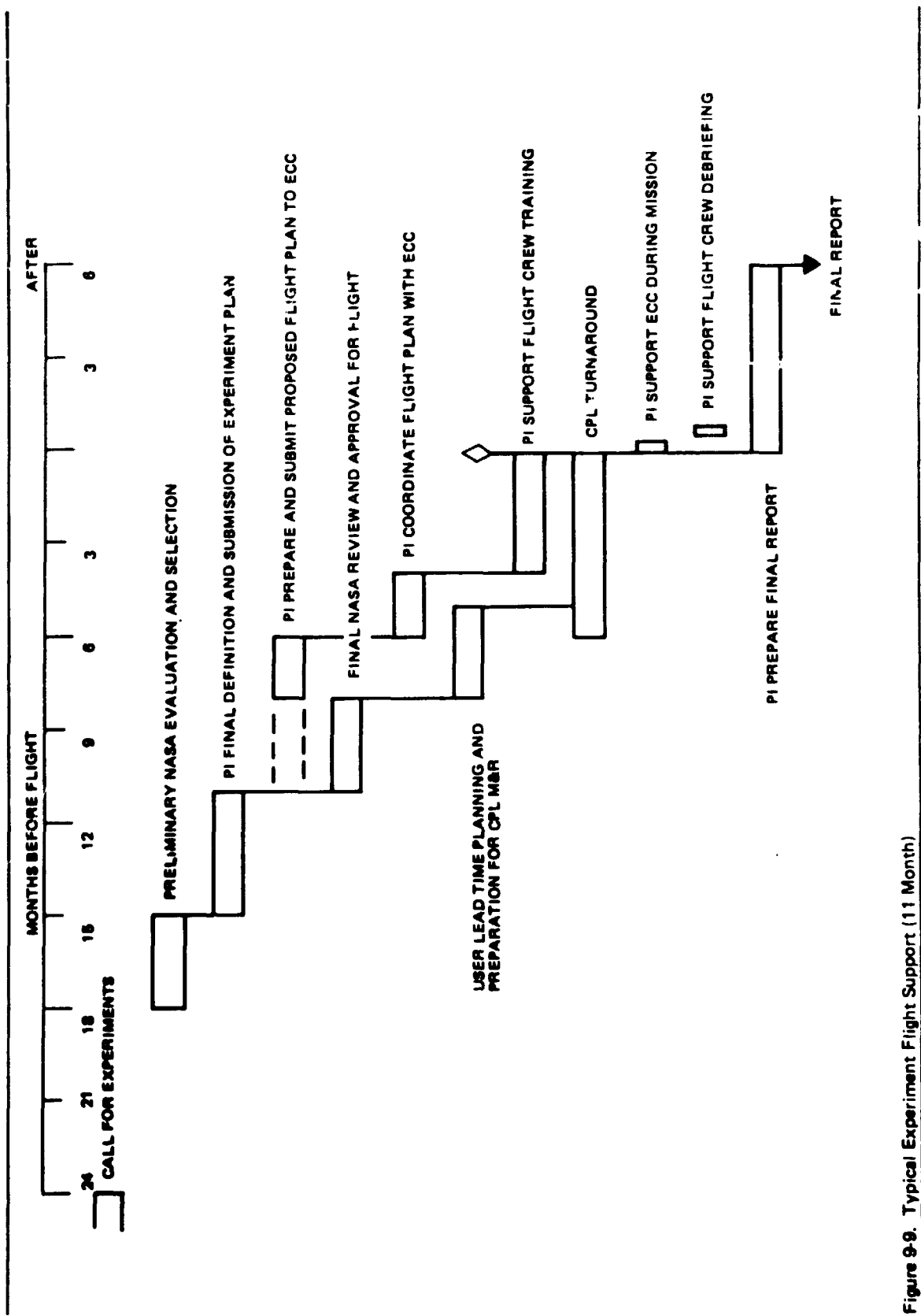
Figure 9-9. Typical Experiment Flight Support (11 Month)

During the 4 months prior to flight, the CPL simulator at the ECC is dedicated to the specific flight configuration and provides two functions: train the astronauts and operate the simulator to develop ground baseline data.

During the mission, the simulator and PI's are made available to support the MCC in case of abnormalities in operation of the CPL in orbit.

After recovery, the PI's will be part of the flight crew debriefing. There are then 6 months scheduled for the PI to prepare and submit his final report.

In an attempt to reduce the lead time for experiments, a second flight support schedule, as shown in Figure 9-10, was developed for flight support operation where the time for the submission of the final experiment plan from the PI's was reduced from 11 to 9 months. This was done by reducing the final selection and review by NASA to 60 days and the contractor lead time to 60 days. It also, unfortunately, reduced the coordination time between the PI and ECC for the preparation for training to one month. These drawbacks lead to the conclusion that the 11-month experiments support operations schedule as shown in Figure 9-9 represents a reasonable minimum time span.

A review of the CPL experiment flight support operations leads to the requirement for a CPL ECC to perform the following functions:

    A.   Coordinate PI flight plans into a mission flight plan and develop required software.

    B.   Train the astronauts

    C.   Obtain ground baseline experiment data

    D.   Support the MCC for problems in real time concerning the CPL in orbit.
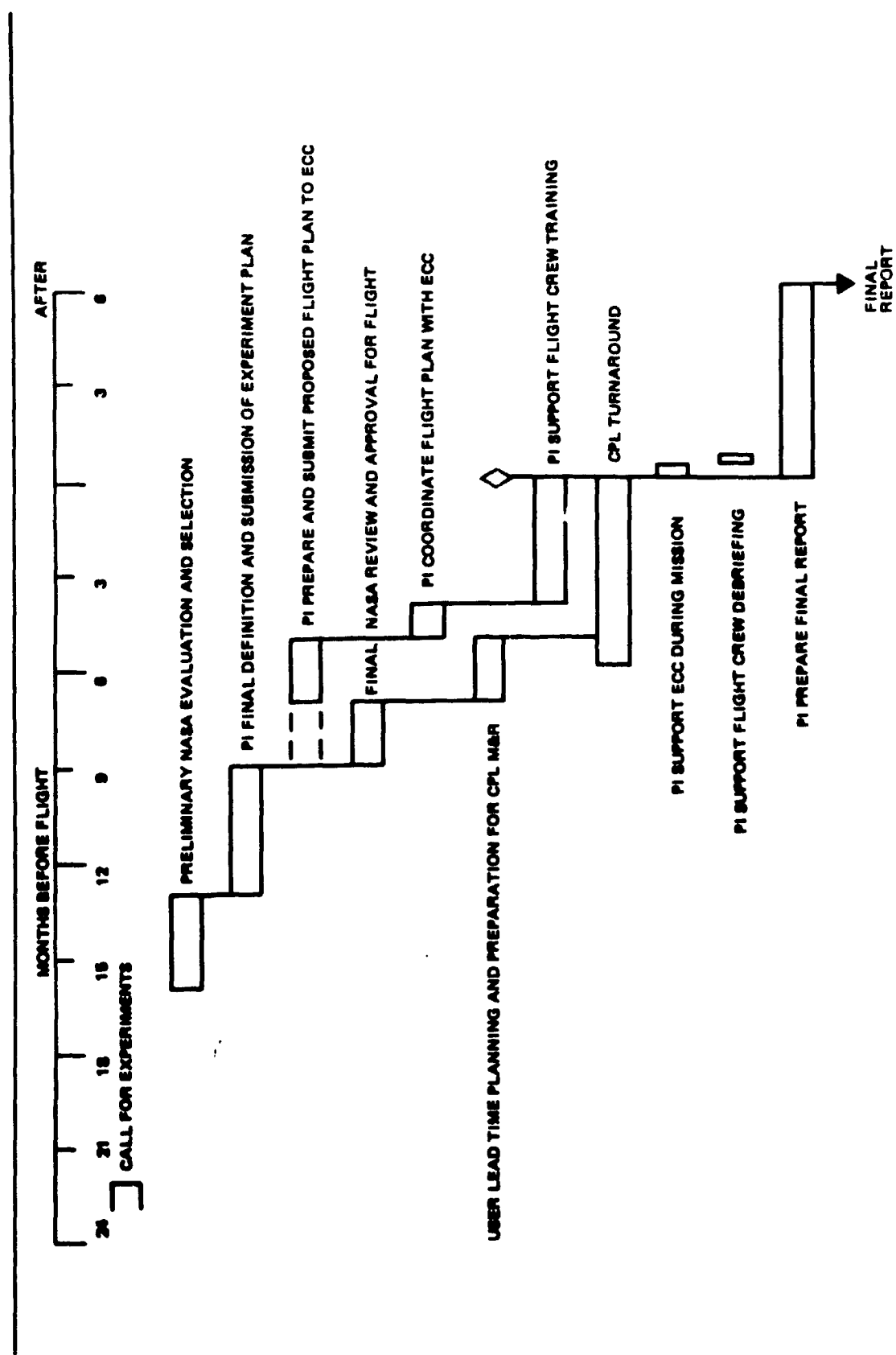
Figure 9-10. Typical Experiment Flight Support (9 Months)

In order to obtain an overview of what the selected schedule would mean in the continuing CPL program, Figure 9-11 was developed showing five cycles of a typical experiment flight support operation schedule waterfalled together on the scheduled 3-month launch centers. Some rather interesting conclusions of the operations and similator training requirements can be drawn by reviewing this waterfall of flights. They are:

A. There will always be a preliminary and final evaluation/selection in process.

B. A preliminary selection is complete one month before the final selection for the previous flight starts. This makes it possible to move an experiment to an earlier flight if conditions so warrant.

C. The ECC requires two simulators to support the flight and flight crew training. These requirements, along with the PI simulator requirements, are examined in detail in the following section.

9.2.3 Simulator Requirements and Utilization

Some form of CPL simulator is required for the following reasons.

A. A high-fidelity simulator (in-flight configuration) should be available during a mission to support the astronauts.

B. Prior to flight, the astronauts require a simulator available for training.

C. Prior to flight, ground baseline experimental data must be obtained. Because of the problems in attempting to obtain these data from the flight article, this becomes a high-fidelity simulator requirement.

D. Prior to their selection for flight, a PI has two different time period when simulator availability is required.

1. During the unfunded experiment definition, it is not mandatory but quite desirable for a PI to have some limited access to a simulator.

2. Once a PI is funded to define an experiment plan, access to a simulator for familarization and understanding is more important.

15 | 12 | 9 | 6 | 3 | | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24

3 4 5 6 7 CALL FOR EXPERIMENTS

3 4 5 6 7 PRELIMINARY NASA EVALUATION AND SELECTION

3 PI FINAL DEFINITION AND SUBMISSION OF EXPERIMENT PLAN
4
5
6
7

FINAL NASA SELECTION FOR FLIGHT 3 4 5 6 7

PI PREPARE AND SUBMIT FLIGHT PLAN TO ECC 3 4 5 6 7

PI/ECC COORDINATE FLIGHT PLAN 3 4 5 6 7

CONTRACTOR LEAD TIME FOR CPL M&R 3 4 5 6 7

PI/ECC SUPPORT FLIGHT CREW TRAINING AND DEVELOP BASELINE DATA
3
4
5
6
7

CPL TURNAROUND
3
4
5
6
7

PI SUPPORT ECC DURING MISSION

PI SUPPORT FLIGHT CREW DEBRIEFING

PI PREPARE FINAL REPORT
3
4
5
6
7

15 | 12 | 9 | 6 | 3 | | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27

PRELIMINARY PI EFFORTS — SIMULATOR AVAILABILITY HELPFUL
3
4
5
6
7

FUNDED PI EXPERIMENT PLAN DEFINITION — SIMULATOR USEFUL
3
4
5
6
7

ECC SIMULATOR AND TRAINING UTILIZATION
ECC/PT FLIGHT PLAN COORDINATION
1 FLT TRN (REF)
2 FLT TRN (REF)
3 4 5 6 7
MISSION SUPPORT

Figure 9-11. CPL Flight Support Operations (Flights 3 to 7)

E. Access to a simulator will enhance coordination in the molding together of various PI flight plans by the ECC personnel.

Requirements A, B, and E require two simulators at the ECC because one simulator would become too restrictive in scheduling while three simulators cannot be justified even when adding the time demands of requirements C and D.

In evaluating alternate approaches for requirements C and D, the following three way tradeoff was conducted. The three alternatives were:

A. Provide mobile CPL simulators to be used by the PI's at their research sites.

B. Provide remote terminals with data displays and controls, to be used by the PI's at their research site.

C. Provide for PI travel to the ECC simulators for familiarization, flight plan development and coordination, and development of ground baseline data.

The providing of the mobile CPL simulators was the most costly option. Use of the remote terminals was the best satisfactory option. PI usage of the ECC simulators proved the most reasonable method of accomplishment of PI efforts. ECC simulator/schedule evaluation showed that PI access to a simulator can be provided on an almost continuous basis. The lower project cost and the increased PI/ECC personnel coordination appear to offset the PI inconvenience of travel to the ECC.

9.2.4 Initial Flight Support Operation Schedule

Figure 9-12 shows an expected initial flight operation schedule for Flights 1 and 2. These flight schedules vary from the typical for several reasons: (1) a longer CPL preparation and checkout for flight is required; (2) a longer crew training time is required; and (3) there is a 6-month period between flights rather than 3 as in the normal operation. The first CPL will be delivered 9 months before flight as compared to the 6-month cycle
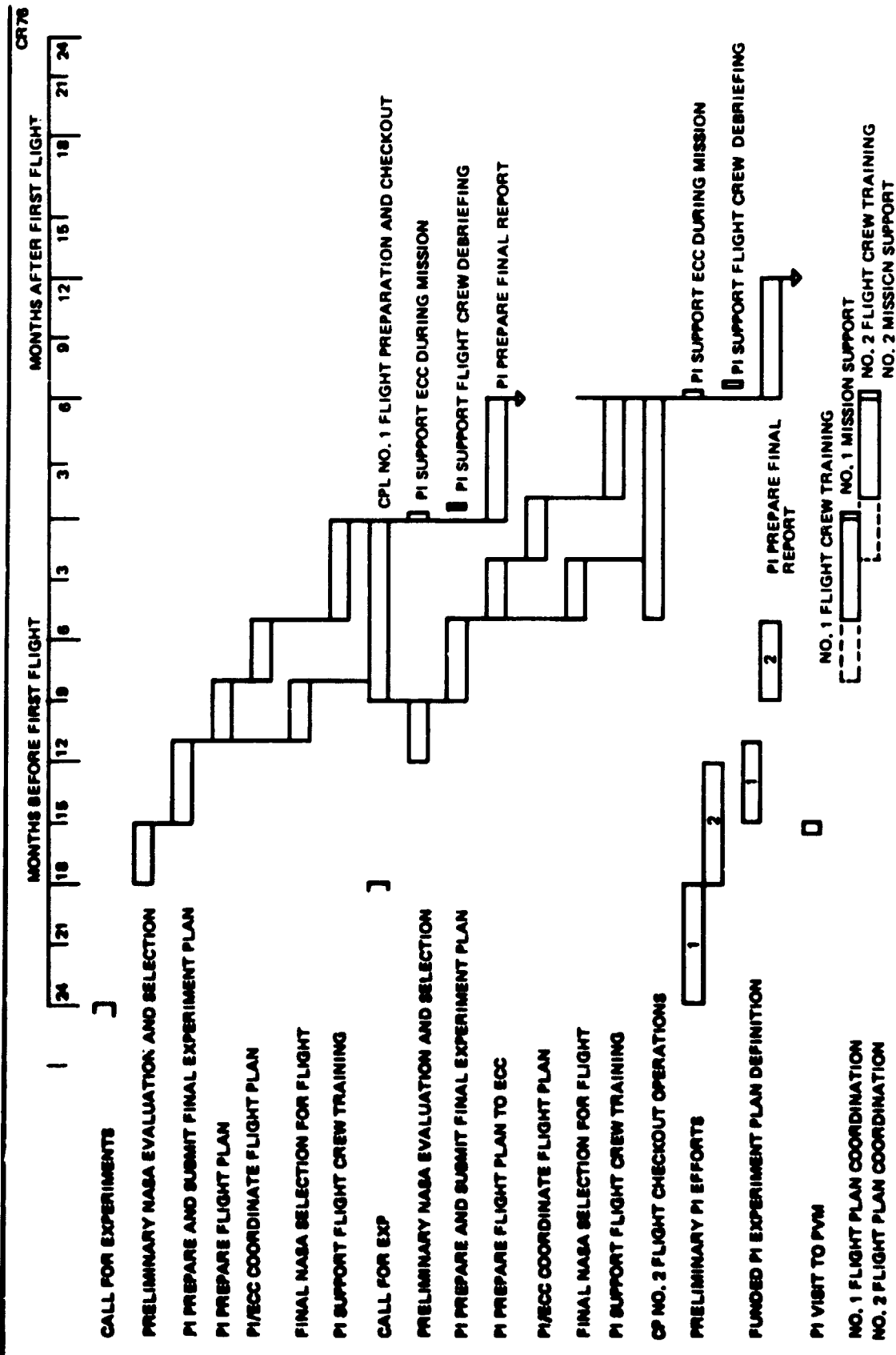
Figure 8-12. Flight Support Operations CPL Flights 1 and 2

in the normal operations. It is anticipated that the CPL configuration will have been firmly defined 8 months before flight. The second CPL is delivered 4 months after the first or 11 months before its flight. This provides additional time for checkout of CPL 2 and the additional chambers and equipment not scheduled for flight in either CPL 1 or CPL 2.

In reviewing the requirements for an possible availability of simulators, the project verification model (PVM) would be transported to the ECC as the flight crew trainer for Flight 1 after its use in interface checkout prior to delivery of the first flight CPL. The second simulator would be economically supplied by providing appropriate cabinetry and components available from the qualification hardware.

In reviewing how to support the first and second set of PI's in their pre-liminary and funded experiment plan activities, it was determined that the PVM would be 3 months into test and available for PI familiarization when the first CPL PI's are selected.

If candidate PI's for Flight 2 could be identified by the time the Flight 1 PI's visited the PVM, a concurrent visit would be feasible. If not approximately a month after start of funded effort, the first CPL simulator would be at the ECC and could be used to support Flight 2 candidate PI's.

Section 10
DATA MANAGEMENT OPERATIONS PLAN

The data management operations plan is based upon the CPL operations plan.
Table 10-1 summarizes the plan itself. It defines the various phases through
which the Data Management System (DMS) Progresses from conception to use,
the responsible contractor or agency and the location of the effort. In the
following sections the mission phases are developed to provide an assessment
of the development and operation of the system.

10.1 MISSION PLANS
Once missions with the CPL, laboratory, and orbiter have begun, DMS mis-
sion plans will repeat a set pattern. Table 10-2 presents a summary of
these plans beginning with the landing of the orbiter and continuing through
experiment operations. Figures 10-1 to 10-8 presents an expansion of the
operations or functions performed by and for the DMS and list the specifica-
tions, procedures, reports, and forms necessary to conduct each mission
segment.

The segments have been divided as follows: (1) recover data; (2) DMS
inspection and checkout; (3) maintenance and repair; (4) configure CPLDMS;
(5) functional verification and test; (6) integrate laboratory and CPL (DMS);
(7) CPL power-up, interface verification; and (8) CPL experiment operation.

Those operations in which the DMS is relatively quiescent such as installa-
tion of the laboratory into the orbiter, transfer to the pad, prelaunch opera-
tions, and ascent are not included, although it is recognized that some minor
functions such as caution and warning monitoring will be continuously
performed.

Table 10-1

DATA MANAGEMENT SYSTEM PLAN

Phase	Responsibility	Location
1) Design	CPL Contractor	Contractor facility
2) Development	CPL Contractor	Contractor/subcontractor facility
3) Test	CPL Contractor	Contractor facility
4) Integration (CPL)	CPL Contractor	Contractor facility
5) Integration (Laboratory and Experiment)	Experiment Integrator	Integration facility (MSFC)
6) Mission Operations		
a. Operation	Experiment Control	MSFC or JSC or KSC
b. Maintenance	Experiment Integrator	Integration facility (MSFC) and/or contractor facility
c. Experiment Integration	Experiment Integrator	Integration facility (MSFC/KSC)
d. System Test	Experiment Integrator	Launch facility (KSC)

LAUNCH FACILITY

| EXPERIMENT CHECKOUT AREA | DATA PROCESSING FACILITY |

CIF

| MISSION ANALYSIS |

| UNIVERSITIES |
| SECONDARY USERS |

FACILITY	OPERATIONS	SPECIFICATIONS
LAUNCH FACILITY (EXPERIMENT CHECKOUT AREA)	RECOVER TAPES	• DATA HANDLING PROCEDURES
(DATA PROCESSING FACILITY)	COPY TAPES	
	SEPARATE CPL DATA	
	COPY AND ANNOTATE PER DATA REQUEST FORMS	• DATA PROCESSING REQUEST FORMS
	ROUTE STATUS DATA TO CIF	• DISPOSITION RECORDS
	TRANSFER REQUESTED TAPES AND HARD COPY TO SECONDARY USERS	• DATA SHIPMENT ADVISORIES
		• INVOICE/SHIPPING DOCUMENTS
		• TAPE LABELING
USER SITE/CIF (MISSION ANALYSIS AREA)	RECEIVE TAPES	• MEASUREMENT PROCESSING REQUEST
	DECOMMUTATE STATUS DATA	
	ANALYZE DATA	
	PREPARE MAINTENANCE AND REPAIR REPORT	• M&R REPORT PROCEDURE
	ROUTE REPORT TO M&R FACILITY	• DISTRIBUTION LISTING
	TRANSFER CPL DMS TO USER SITE	• CPL (DMS) LOG

Figure 10-1. Mission Plan 1 - Recover Data

FACILITY	OPERATIONS	SPECIFICATIONS

CIF/USER SITE

RECEIVING AND SHIPPING	MAINTENANCE AND REPAIR AREA

SUBCONTRACTORS

EQUIPMENT MANUFACTURER

USER SITE/CIF (RECEIVING)

RECEIVE CPL (DMS)

VISUAL INSPECTION

- SHIPPING INSTRUCTIONS
- RECEIVING INVOICE
- INSPECTION PROCEDURE

(MAINTENANCE AND REPAIR AREA)

TRANSFER TO M&R AREA

REVIEW M&R REPORT

CONTINUITY/COMPATIBILITY VERIFICATION

CONNECT GSE

CALIBRATE
RUN FUNCTIONAL TESTS
REDUCE DATA

PREPARE REMOVAL TAGS
REMOVE EQUIPMENT

PERFORM COMPONENT TEST

PREPARE FAILURE AND REJECTION REPORTS

TRANSFER EQUIPMENT TO REPAIR FACILITIES

SHIP TO EQUIPMENT MANUFACTURER

- TEST PROCEDURE

- CALIBRATION PROCEDURE
- TEST PROCEDURE
- MEASUREMENT PROCESSING REQUEST

- REMOVAL PROCEDURE

- COMPONENT TEST PROCEDURES

- FRR PROCEDURE

- SHIPPING INSTRUCTIONS

- SHIPPING INSTRUCTIONS

Figure 10-2. Mission Plan 2 - DMS Inspection and Checkout

SUBCONTRACTORS	CIF/USER SITE			
EQUIPMENT MANUFACTURING	RECEIVING INSPECTION	MAINTENANCE AND REPAIR	STOCK ROOM	INTEGRATION AND CHECKOUT
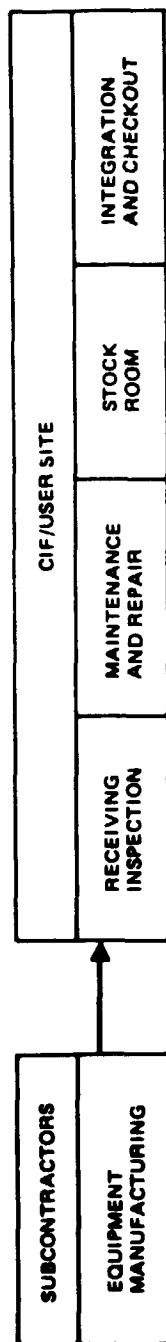
FACILITY	OPERATIONS	SPECIFICATIONS
SUBCONTRACTORS (EQUIPMENT MANUFACTURER AND TEST)	COMPONENT TEST FAULT DIAGNOSIS REPAIR AND TEST FAILURE ANALYSIS AND REPAIR REPORT	• TEST PROCEDURE • REPORT PROCEDURE
USER SITE/CIF (REPAIR FACILITY)	MECHANICAL REFURBISHMENT AND PAINT MINOR PART REPLACEMENT TEST FAILURE ANALYSIS AND REPAIR REPORT	• PAINT SPECIFICATIONS • COMPONENT SPECIFICATIONS • TEST PROCEDURE • REPORT PROCEDURE
(RECEIVING INSPECTION)	COMPONENT TEST RETURN TO STOCK	• TEST PROCEDURE
(MAINTENANCE AND REPAIR)	COMPONENT TEST INSTALLATION TRANSFER CPL (DMS) TO INTEGRATION AND CHECKOUT	• TEST PROCEDURE • INSTALLATION PROCEDURE • TRANSFER INSTRUCTIONS

Figure 10-3. Mission Plan 3 - DMS Maintenance and Repair

CIF/USER SITE		
INTEGRATION AND CHECKOUT AREA	STOCK ROOM	COMPUTER/ PROCESSING FACILITY

FACILITY

CIF/USER SITE

(CHECKOUT FACILITY)

(COMPUTER PROCESSING)

(CHECKOUT FACILITY)

OPERATIONS

ANALYZE DRAWINGS

SUBMIT EQUIPMENT REQUESTS

DRAW EQUIPMENT FROM STOCK ROOM

INSTALL EQUIPMENT

RECEIVE EXPERIMENT SOFTWARE REQUESTS AND FLOWS

DEVELOP SOFTWARE MODULES

VERIFY

SUBMIT SOFTWARE REQUESTS

RECEIVE TAPES

REPROGRAM SIMULATOR

REPROGRAM DMS

VERIFY

SPECIFICATIONS

- DMS SPECIFICATIONS (CONFIGURATION)

- MATERIAL REQUEST FORMS

- INSTALLATION DRAWINGS
- INSPECTION PROCEDURES

- SOFTWARE SPECIFICATIONS

- VERIFICATION PROCEDURES

- REQUEST FORMS

- PROGRAMMING INSTRUCTIONS

- TEST REQUIREMENTS

Figure 10-4. Mission Plan 4 - Configure CPL (DMS) for Next Mission

LAUNCH FACILITY

MSOB

CIF/USER SITE

CHECKOUT FACILITY | RECEIVING AND SHIPPING | DATA PROCESSING FACILITY

FACILITY

CIF (USER SITE)

(CHECKOUT FACILITY)

(DATA PROCESSING)

(CHECKOUT FACILITY)

(RECEIVING AND SHIPPING)

OPERATIONS

CONTINUITY/COMPATIBILITY VERIFICATION

CONNECT SIMULATOR

CALIBRATION SHEETS/DATA REQUESTS TO DATA PROCESSING

POWER CHECKS

DMS CALIBRATION

DMS CHECKOUT

SUBSYSTEM CHECKOUT

ACTIVATION TEST

DEACTIVATION TEST

TRANSFER TAPES TO DATA PROCESSING

REDUCE DATA

ANALYZE DATA

DISCONNECT SIMULATOR

TRANSFER TO LAUNCH FACILITY

SPECIFICATIONS

• TEST PROCEDURE

• FORMAT SPECIFICATION

• TEST PROCEDURES

• MEASUREMENT PROCESSING REQUESTS

• STATUS REPORT

• CPL (DMS) LOG

Figure 10-5. Mission Plan 5 - DMS Functional Verification and Test
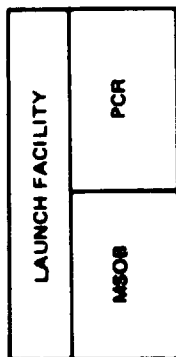
LAUNCH FACILITY

MSOB	PCR

FACILITY

LAUNCH FACILITY (MSOB)

OPERATIONS

RECEIVING INSPECTION

CONTINUITY/COMPATIBILITY CHECKS

PROGRAM LABORATORY COMPUTER

VERIFY

CONNECT CPL (DMS)

POWER CHECKS

DMS CHECKOUT

SYSTEM CALIBRATION

SYSTEM CHECKOUT

ANALYZE DATA

CLEAR PROBLEMS

INSTALL IN SPACELAB

TRANSFER TO PCR

SPECIFICATIONS

• INSPECTION PROCEDURE

• TEST PROCEDURE

• PROGRAMMING PROCEDURE

• TEST PROCEDURES

• CALIBRATION PROCEDURES

• TEST PROCEDURE

• STATUS REPORT

Figure 10-6. Mission Plan 6 - Integrate Lab, CPL (DMS)

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┌──────────────┐        ┌──────────┬──────────┐        ┌──────────────┐
│  CPL POWER   │────────▶│   CRT    │   KBD    │◀───────▶│ MANUAL SWITCHES│
│  SUPPLY AND  │         ├──────────┴──────────┤         ├──────────────┤
│ DISTRIBUTION │         │         DMS         │         │     CPL      │
│              │         │                     │         │  EQUIPMENT   │
└──────────────┘        └─────────────────────┘        └──────────────┘
```
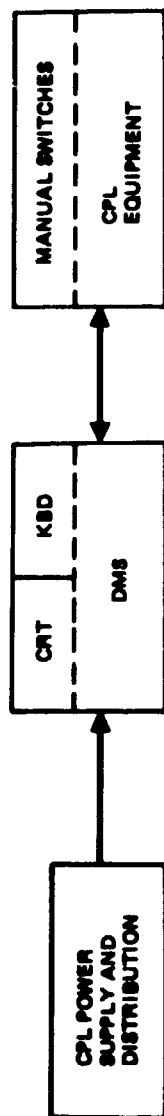
FACILITY   OPERATIONS   SPECIFICATIONS

SPACELAB   CPL SETUP   • CHECKLIST-STOWED EQUIPMENT
                                                             MOUNTED AND CONNECTED

                         INITIAL CONDITIONS VERIFICATION   • CHECKLIST-ALL MANUAL SWITCHES
                                                             AND CONTROLS DOWN, OFF, OR
                                                             NOMINAL POSITION

                         AUTO CHECKOUT VERIFICATION   • SPACELAB SUPPLY VOLTAGES
                                                             NOMINAL

                                                           • VOLTAGE AND CURRENT MONITOR
                                                             PROGRAM ACTIVE

                                                           • AUTO SWITCHING SEQUENCE
                                                             PROGRAM LOADED

                         MANUAL CHECKOUT VERIFICATION   • SPACELAB SUPPLY VOLTAGES NOMINAL

                                                           • VOLTAGE AND CURRENT MONITOR
                                                             PROGRAM ACTIVE

                                                           • MANUAL SWITCHING SEQUENCE
                                                             CHECKLIST DISPLAYED

                         POWER-UP COMPLETE VERIFICATION   • SPACELAB SUPPLY VOLTAGES NOMINAL

                                                           • CPL POWERED UNITS ON VOLTAGE AND
                                                             CURRENT NORMAL

Figure 10-7. Mission Plan 7 - CPL Power-Up, Interface Verification

10-9

FACILITY	OPERATIONS	SPECIFICATIONS
SPACELAB	CPL CHECKOUT	• CPL POWER-UP COMPLETE • AUTO CONTROL AND MONITOR FUNCTIONAL VERIFICATION PROGRAM-EACH CIRCUIT VERIFIED OPERATIONAL SEQUENTIALLY • MANUAL CONTROL AND MONITOR FUNCTIONAL CHECKLIST-EACH LISTED ITEM VISUALLY VERIFIED OPERATIONAL
SPACELAB	EXPERIMENT PREPARATION	• CPL CHECKOUT COMPLETE • CAMERAS AND RECORDERS LOADING • CPL PURGE SEQUENCE PER AUTO PROGRAM AND CHECKLIST • EXPERIMENT AND INITIAL CONDITIONS DEFINITION PER KEYBOARD AND VOICE INPUTS
SPACELAB AND ORBITER	EXPERIMENT RUN	• EXPERIMENT PREPS COMPLETE • AUTO START PER KEYBOARD INPUT • AUTO RUN PER PROGRAM TAPE • MANUAL SUPPORT PER CRT DISPLAY CHECKLIST • DATA SUPPLEMENT PER KEYBOARD AND VOICE INPUTS • REAL-TIME DATA TRANSFER VIA TM, VIDEO, AND AUDIO DOWNLINK • RUN INTERRUPT VIA KEYBOARD INPUT
SPACELAB	CPL SHUTDOWN	• FILM AND TAPE REMOVAL AND STORAGE PER CRT CHECKLIST • CPL PURGE PER AUTO PROGRAM SEQUENCE • MANUAL CONTROL SHUTDOWN PER CRT CHECKLIST • AUTO POWER-DOWN PER PROGRAM SEQUENCE • MANUAL CLEANUP PER CRT CHECKLIST • EQUIPMENT REMOVAL AND STORAGE PER CRT CHECKLIST

Figure 10-8. Mission Plan 8 - CPL Experiment Operation

Table 10-2 (Sheet 1 of 2)

DMS MISSION PLAN POST-ORBITER LANDING

(Mission Ground Operations)

Time (hr)	CPL Operations	DMS Operations Summary
0	Landing	
80 - 120	Recover data, CPL to CIF or user site	___ Analyze data tapes ___ Develop fault list ___ Develop suspect component list
120 - 160	CPL inspection and checkout	___ Run checkout routines ___ Verify anomalies, failed components
160 - 240	Avionics M&R	___ Remove failed components ___ Test ___ Repair or Scrap ___ Refurbish worn equipment
240 - 280	Configure CPL for next mission	___ Obtain new calculations data ___ Enter into programs ___ Reprogram processor ___ Verify
280 - 320	Transfer to CIF checkout	
320 - 360	Preparation for system integration	___ Interface continuity compatibility checks
360 - 400	Connection to simulator	___ Load simulator checkout, operation, display programs
400 - 440	DMS functional verification and test	___ Power checks ___ DMS checks
440 - 600	Other system tests	___ Operate DMS in support
600 - 760	Mate, Ship to MSOB, and service	
760 - 800	Integrate lab, CPL, and verify	___ Interface continuity, compatibility tests ___ Load Programs in lab system ___ Verify
800 - 880	Combined system tests	___ DMS/laboratory operation

Table 10-2 (Sheet 2 of 2)

DMS MISSION PLAN POST-ORBITER LANDING

(Reference Task 7.3 - Mission Ground Operations)

Time (hr) CPL Operations		DMS Operations Summary
On-Orbit		
1080 - 1120	CPL power-up, interface verification	___ DMS checkout ___ DMS calibration
1120	Experiment operation	___ DMS operation

10.2 REQUIREMENT ANALYSIS

On-orbit processing requirements were found to be generally limited to data acquisition, status monitoring, data annotation, storage/transfer, and control. A summary of data requirements and the contrasting capabilities afforded by Spacelab-provided systems is shown in Figure 10-9. The following comments apply:

A. The measurement quantity, even if doubled, is not large and can be accommodated by three remote acquisition units (RAU's) or two digital

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DATA ACQUISITION METHODS	CPL (MIN)	CPL (MAX)	SPACELAB CONSTRAINT
MEASUREMENT QUANTITY	98	200	< 64 ANALOGS/RAU < 128 ANALOGS/DIU
MEASUREMENT RATE (KBPS)	0.44	1	TBD, 500
COMPUTER MEMORY (KWORDS)	8	TBD	TBD, 13
COMPUTER OPERATION RATE (ADDS/uSEC)	0.001	TBD	05
VIDEO BANDWIDTH (MHz)	4	32	8
VIDEO STORAGE (REELS)	1	4	1 (MIN)
COMMUNICATION RATE (STDN) (KBPS)	< 25	TBD	25,256
COMMUNICATION RATE (TDRS) (MBPS)	NOT REQ	NOT REQ	50
COMMUNICATION VIDEO (CHANNELS)	1	1	1
DIGITAL STORAGE (REELS)	1	2	1 (MIN)
UPLINK COMMAND (KBPS)	2	2	2
VOICE CHANNELS	1	2	2
ALPHANUMERIC/GRAPHIC DISPLAYS	1	2	2

Figure 10-9. On-Orbit Data Processing Summary

interface units, terms used at various times to describe multiplexer and A/D hardware.

B. The measurement (data) rate is miniscule when contrasted with the Spacelab bus rate of 1 or 2 megabits (minimum 500 kbps bus data rate).

C. Computer memory capacity for CPL control should not exceed 8,000 words. Current references do not provide a clear-cut memory capability.

D. The listed computer add time of 2 μsec (0.5 add/sec) is far in excess of required operation rates which do not appear to exceed 1 msec.

E. The minimum bandwidth of 4 MHz for black and white TV could increase. However, the laboratory is sized to handle color TV (6 MHz).

F. Assuming use of TDRS, one video tape reel capable of recording for 90 minutes and then dumped could potentially satisfy experiment requirements, since some experiments last a minimum of 5 hours (ice crystal growth), three tapes and one backup would assure continuous reading.

G. Since one digital tape will suffice to record an entire mission's data, the only requirement for transmission is to provide data to support personnel in Mission Control at a dump rate some multiple of 1 kbps. The laboratory capability is 25 and 256 kbps on separate lines transmitted to the STADN network.

H. A TDRS link at 50 Mbps is available.

I. A video channel of 5 to 6 MHz (assuming color TV) is required and utilized.

J. A ground-to-laboratory link is desired for transfer of program changes.

K. An intercom for at least one and preferably two men is needed.

L. Alphanumeric and graphic displays are required and available for experiment control, checkout, and procedure presentation.

Based on the foregoing, the laboratory appears capable of accommodating all CPL processing requirements. However, two general requirements exist which affect this conclusion: (1) control and display equipment must be located at the CPL chambers to allow the crew to perform manual operations while monitoring experiment status; (2) provision for the simulation of laboratory equipment during experiment development must be made. These requirements have a major impact on the manner in which processing functions are actually allocated.

10.3 PROCESSING ALLOCATION AND FLOWS

The CPL data processing functions are listed in Figure 10-10. Functions are allocated on the basis of trades. Some ambiguity exists in the data display and data operations categories due to the shared nature of the operation; i.e., the crew control or input request devices are located at the console while the actual software and hardware providing the services are part of the Spacelab equipment complement. At present, the capability to add these peripherals is not available in the ERNO design. However, the interfaces provided for equipment located in the Payload Specialist's Station could be switched to the CPL console following crew ingress into the laboratory.

The basic flow of the experiment from conception through flight is shown in Figure 10-11. It emphasizes those operations involving the generation and processing of data. The flow overlays those facilities where operations take place, establishing where provisions for supporting functions must reside. It should be noted that the flow represents the initial CPL development and integration. Subsequent missions would bypass the integration facility
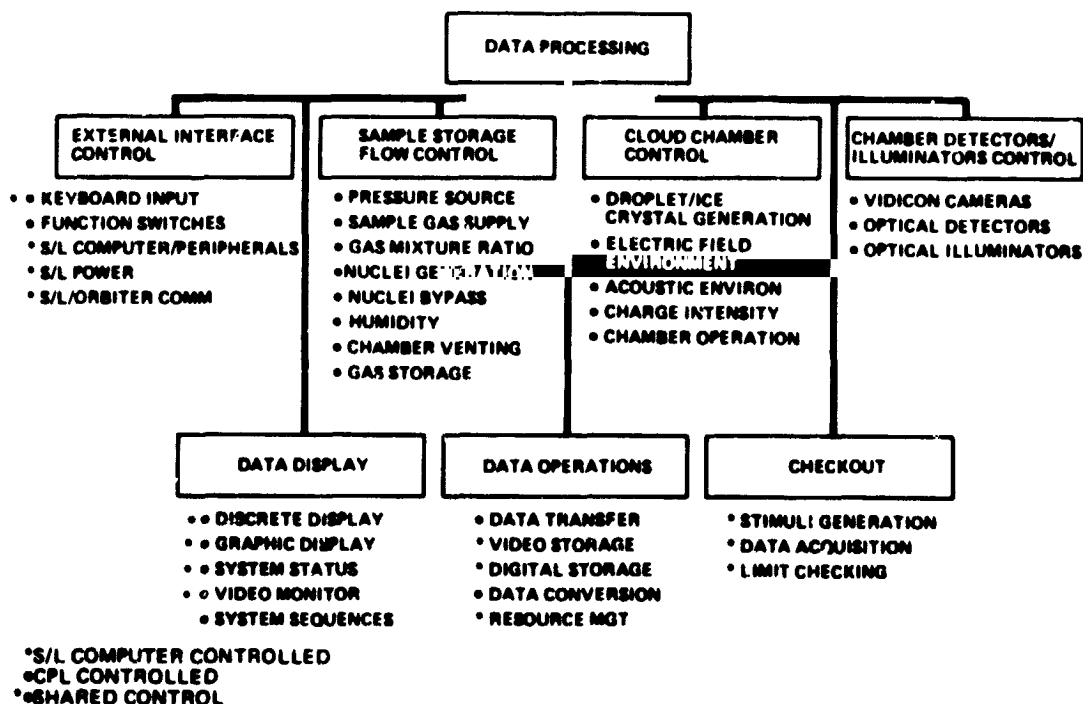
Figure 10-10. CPL Function Allocation
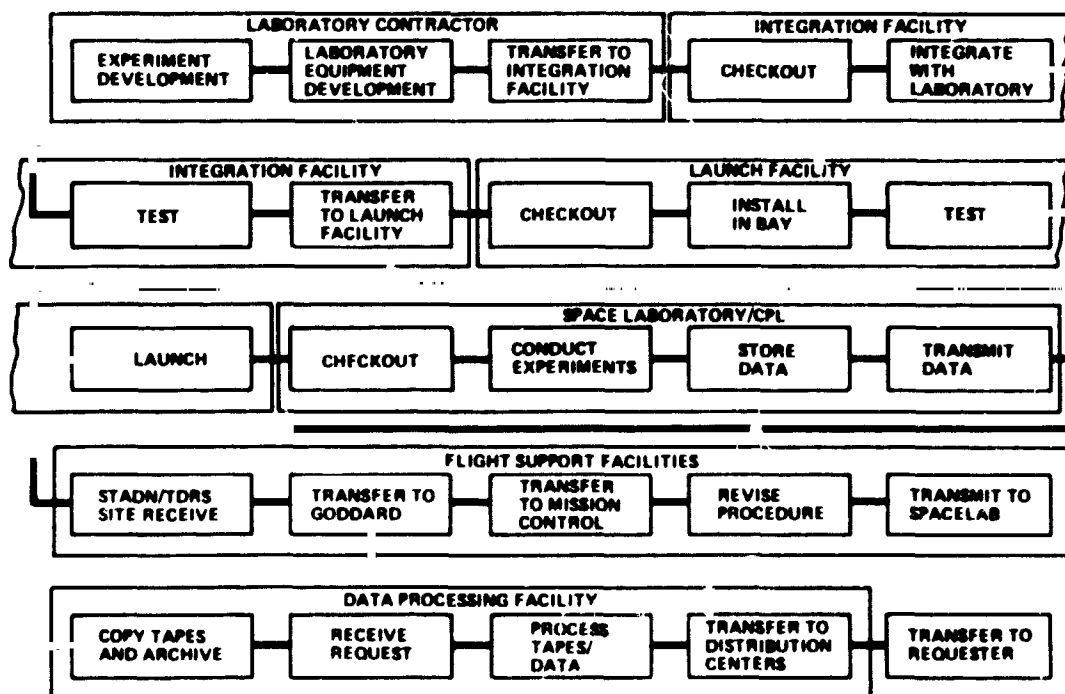
Figure 10-11. Primary Experiment/Data Flow

(assumed to be located at MSFC) and equipment would be refurbished at the site defined for such operations.

A second-level flow for the Spacelab/CPL facility which defines internal processing operations is shown in Figure 10-12. The operations are defined for the four classic types of data involved with experiments: (1) control signals, (2) scientific data, (3) status data, and (4) caution and warning signals. Of the four only the first three are of concern from a CPL data handling standpoint since C&W signals are few in number, have no high-frequency components and are handled exclusively by the Spacelab system. The video signals, which are a part of the scientific data, also tend to require little analysis since handling options are few and their accommodation is straight-forward. Remaining then are control, scientific, and status data which are digital in nature and require matching of data, response, and operation rates at all interfaces. Figure 10-12 reorients the laboratory data management flow along operational lines and provides some additional detail. It also

a) LABORATORY DATA MANAGEMENT FLOW

b) CPL CONTROL AND DATA HANDLING FLOW
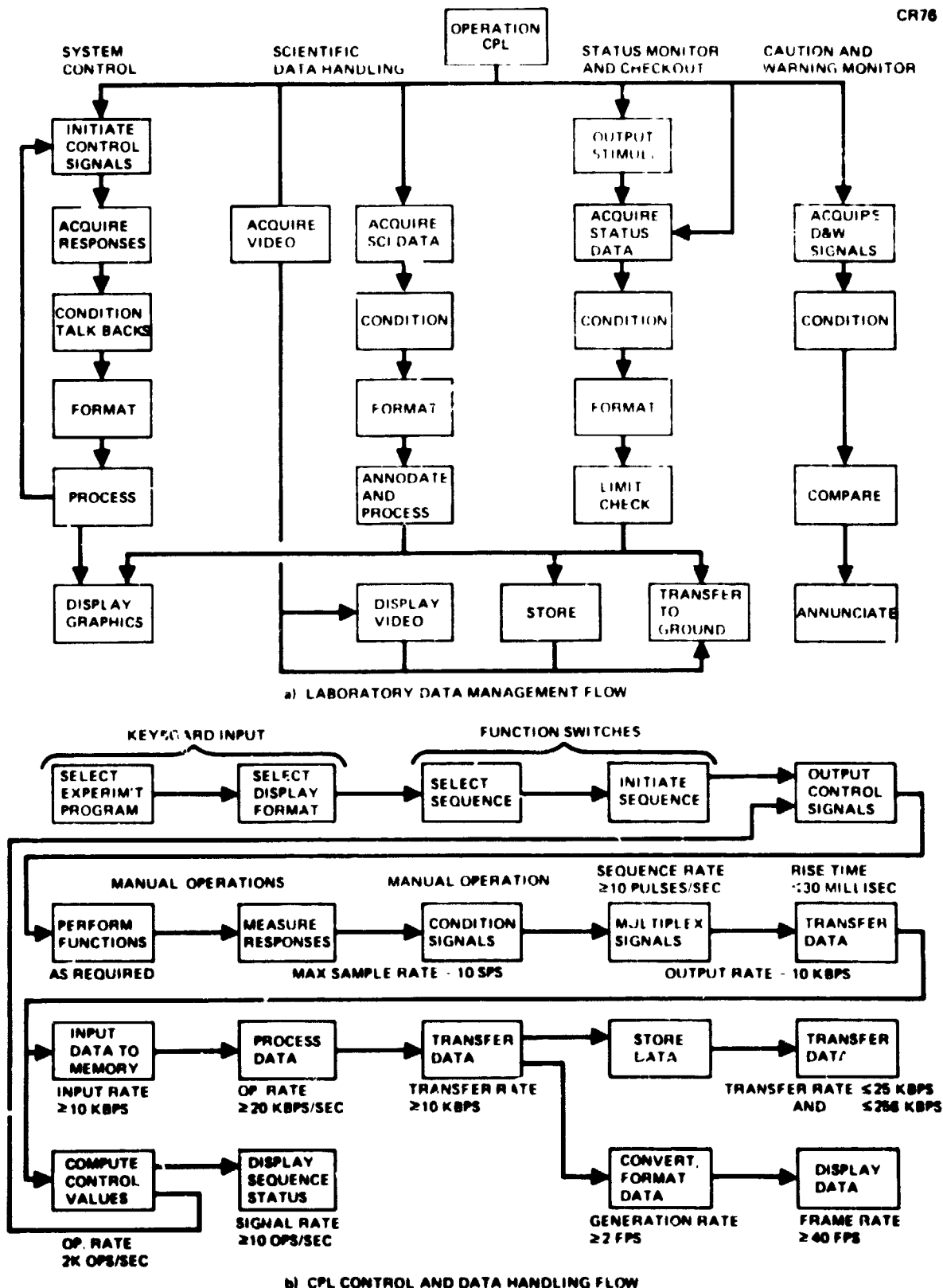
Figure 10-12. Internal Processing Flows

recognizes the allocation of functions as defined by Figure 10-10 in that separate paths are provided for control and status/scientific data. For each of the operations where timing is of importance, initial rough estimates of rates or response times have also been established.

Beginning with the sequencing of control signals, a rate of 10 control outputs per second has been established based upon requirements for controlling chamber pressures. This figure, while slow, appears adequate and is commensurate with reasonable valve response times of 30 msec. The maximum data sampling rate of 10 sps is derived from measurement monitoring requirements and the data transfer rate of 10 kbps is arrived at by assuming 100 measurements, all at the worst-case sample rate with each quantized at 10 bits per sample. The data processing rate of 20 kbps/second results from assuming a worst case of 200 measurements, each sampled 10 times per second with each sample requiring 10 instructions for its processing. Estimating 10 percent of these measurements will be used for control provides an initial rate of 2 kbps. Digital tape reproduce rates are set by Shuttle constraints and will provide the basis for record/reproduce speed ratios. The display rate of 40 fps is established by flicker-free viewing requirements. The generation rate of 2 fps obviously requires a refresh capability within the display.

10.4 DMS EQUIPMENT OPERATION

The data management system (DMS) consists of that equipment allowing development and operation of the CPL with a minimum of special-purpose simulation or support and that portion provided by the Spacelab. This division is illustrated in Figure 10-13 by the dashed line. The interface adapter provides interface compatibility between the two system elements with the exception of the video components which interface directly with breakout boxes provided by Spacelab. Operations of the Spacelab functions during development would be performed by standard laboratory equipment.

The processor performs all valve sequencing operations with the exception of those few performed manually. Control would be exercised interactively with the operator by incorporating "Requests for Data" or "Halt" points
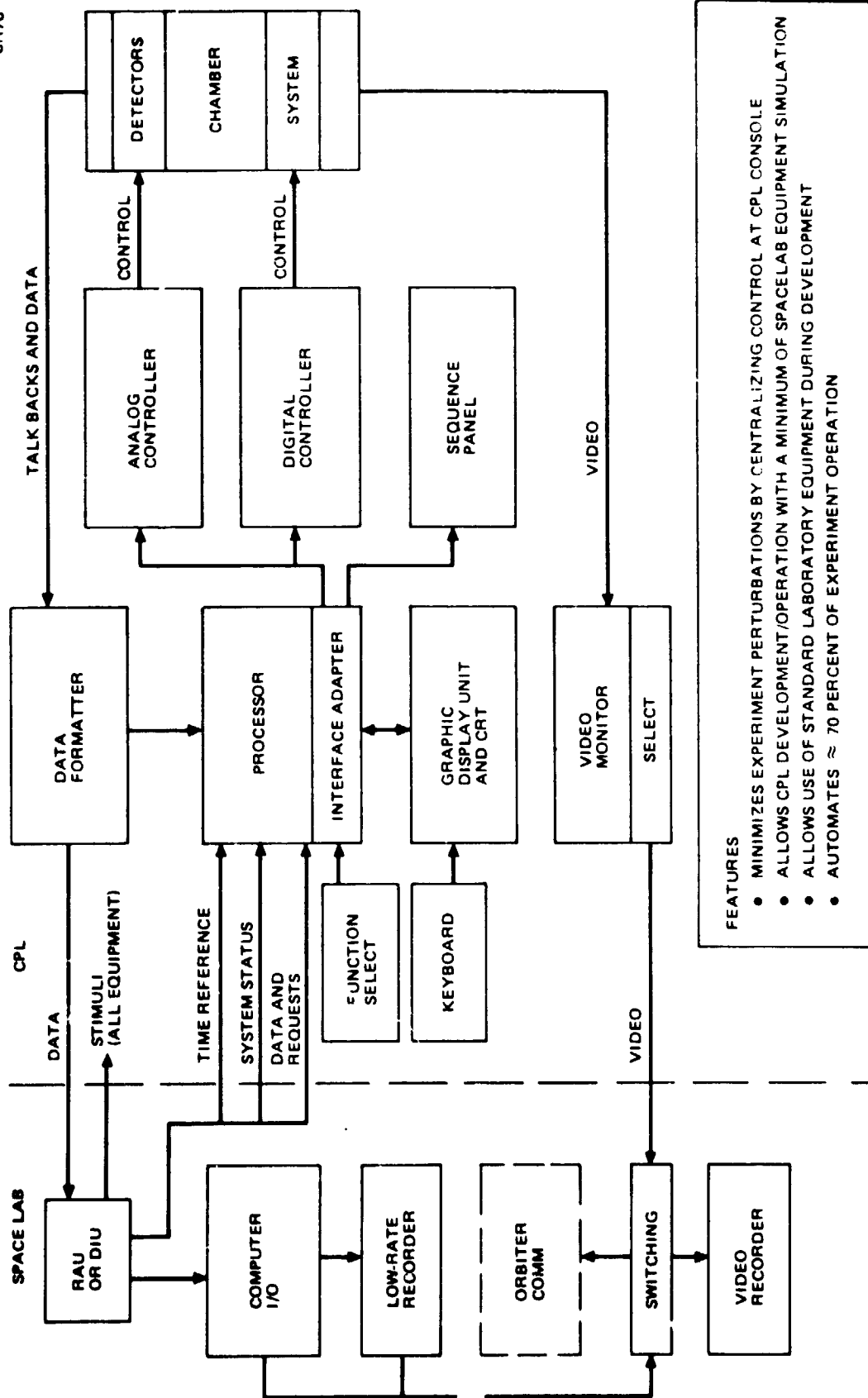
Figure 10-13. Data Management Block Diagram

within the programs. These would allow an opportunity to modify the program data base or select alternate continuation sequences depending upon each experiment's particular needs. They would also provide a "Hold" period to allow the operator time to consult procedures or the progress of the experiment to that point. Operator control would be exercised via the keyboard and function select keys. Information would be displayed on the graphics display unit and by the sequence panel which would contain a diagram of the system and lights indicating the status of the experiment in progress. The processor would output commands via the interface adapter to either the analog or digital controller. The controllers would provide either analog or digital (discrete) signals to the appropriate valves, detectors, or CPL control devices.

Talkbacks from these units would be continued to have the proper signal characteristics for data acquisition by the formatter. This unit would sample the signals in a preprogrammed sequence, provide the appropriate talkbacks

to the processor, and route all data to the remote acquisition unit (RAU) in serial digital form. The data would periodically be accessed by the Spacelab computer and routed to either the low-rate recorder or brought into memory. The latter procedure would be performed if a checkout sequence was being performed. The computer also is the repository for all experiment procedures, display formats, and provides the commands controlling the status of the CPL processor entered via the keyboard.

The following paragraphs present a detailed description of the equipment operations.

10.4.1 Recording

All activities connected with the operation of the on-orbit experiment program will be recorded on tape or film. Tape recordings will include the scientific data produced during the conduct of a given experiment, the measurements indicating the health of the experiment equipment and the annotation data providing equipment status (on-off) and setting values (lens position), time of day, film or tape consumption, etc. The data will be provided in digital format at approximately a 1 kbps and as video at about 5 MHz.

Analysis of recorder requirements is complicated by the present level of laboratory definition and some uncertainty as to how the STDN network will be used as secondary support for low-earth-orbit vehicles and payloads. The Spacelab baseline provides a high-rate digital recorder (30 Mbps), a low rate (1 Mbps) recorder as an optional feature and an analog (video) recorder. Although not specified, it is assumed that the low-rate recorder is connected to the computer I/O and that CPL data would be time multiplexed with other experiment data. In this case, only the data rate and record times need be specified.

If this option is not provided, it will be necessary for the CPL to provide its own digital recorder or for the laboratory to provide FM multiplexing equipment to allow access to the high-rate recorder. Given the former alternative, the following analysis may be made. Since the digital data rate is small, a correspondingly slow lower second speed should be selected to reduce tape expenditure. The lowest speed available on a standard recorder is 15/32 ips. The reproduce speed should be the highest compatible with the communications system capability or 256 kbps, if operation with the STDN network is assumed; use of the 1.02-Mbps "dump" capability would preclude the simultaneous transmission of TV.

In actual practice the speed change range is somewhat limited and since use of a standard laboratory recorder is contemplated to reduce costs, a speed selection of 3-3/4, 7-1/2, 30, 60, and 120 ips is more likely to be available. However, a maximum ratio of 32:1 would only produce 32 kbps, far short of our goal. Since there is also some question as to the availability of the 256-kbps data line for use by a single experiment and a 25-kbps line is available, a more judicious choice would be to use this line with a speed ratio of 16:1 producing 16 kbps. An average pass time in low earth orbit of 8 minutes would allow the transfer of 128 minutes or about 2 hours of data and three passes would probably transfer a complete days accumulation to the ground. Alternatively, 10 hours per day for 6 days of recording at the 1-kbps rate would only produce 2.16×10^7 data bits, which is well within the capacity of a single 10-1/2-in. reel.

It is recommended at this time that the availability of a laboratory low-rate digital recorder be assumed. The recommendation should then be reassessed at the CPL PDR and CDR reviews. Should the assumption prove invalid, the incorporation of a recorder into the CPL at a late date would be relatively simple as long as a port is provided on the data formatter (acquisition) unit.

No data are presently available as to how the video cameras will be operated -- in a burst mode or continuously. However, both operating modes are expected due to the divergent nature of the CPL experiments. Since the laboratory video recorder will be limited to about 30 minutes, the net effect of the burst mode would be to extend recorder operation without tape change for the entire day. With the availability of the TDRS, it is also possible to transmit the recorded video to the ground after which the erase/record sequence would be resumed.

It is doubtful that this latter procedure would be acceptable since reproduce times are equivalent to record times due to the inability to change recorder speeds and an interruption of the recorder's availability could also interrupt the experiment. Tape recorder playback should probably await the completion of the days experimentation.

10.4.2 Data Processing

The CPL processing requirements primarily entail those operations for experiment control and sequencing and those provided to display information to the experimentor in a particular format or manner. The analysis of control operations was initiated by developing timelines for the operation of the CPL system and various cloud chambers and then defining semi-detailed flows for each of the timeline operations. From the flows, the number of discrete instructions to perform a sequence or computation could be estimated together with the approximate size of the data base. It also thought that display and other processing requirements could be better estimated by observing when a major procedural change occurred.

A timeline was first eatablished for aerosol generation as shown in Figure 10-14. A flow was then developed for each step of the timeline as shown in Figure 10-15 based upon the subsystem defined by Figure 10-16. The
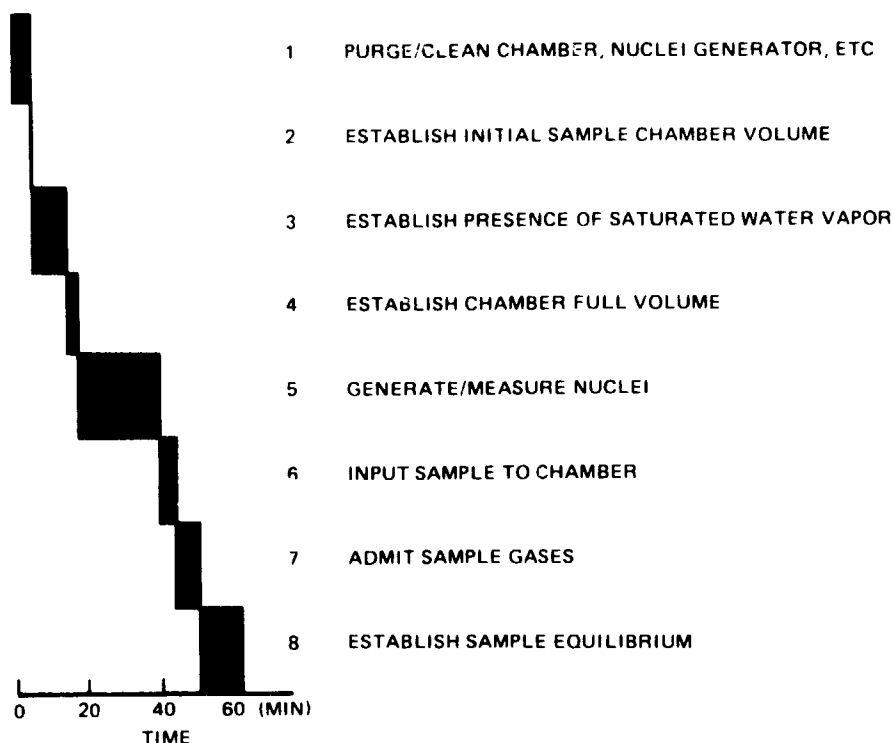
Figure 10-14. Aerosol Generation Timeline

number of control operations was found to total 68 with some functions performed more than once. Twenty-one computations involving time, pressure, or temperature are made in an iterative fashion prior to performing a next operation. By count, 189 instructions would be required to program the sequence yielding a factor of about three instructions per operation. Forty words of storage hold the entire data base such that total program storage requirements should occupy no more than 500 words of memory assuming 50 percent spare capacity.

Experiment descriptions were reviewed and timelines for expe..ments 2, 5, 9 (which use the static diffusion ice chamber), 13 (expansion chamber) and 20 (general chamber) were developed. It was observed that the majority of experiment run times did not exceed 60 to 80 minutes although a run time of 8 hours would not be unusual, particularly for ice crystal formation. The original intent was to develop a flow for each chamber type in order to obtain a complete sampling prior to determining maximum processing requirements. This was precluded by the complexity and size of the experi-

STEP 1 — PURGE AND CLEAN
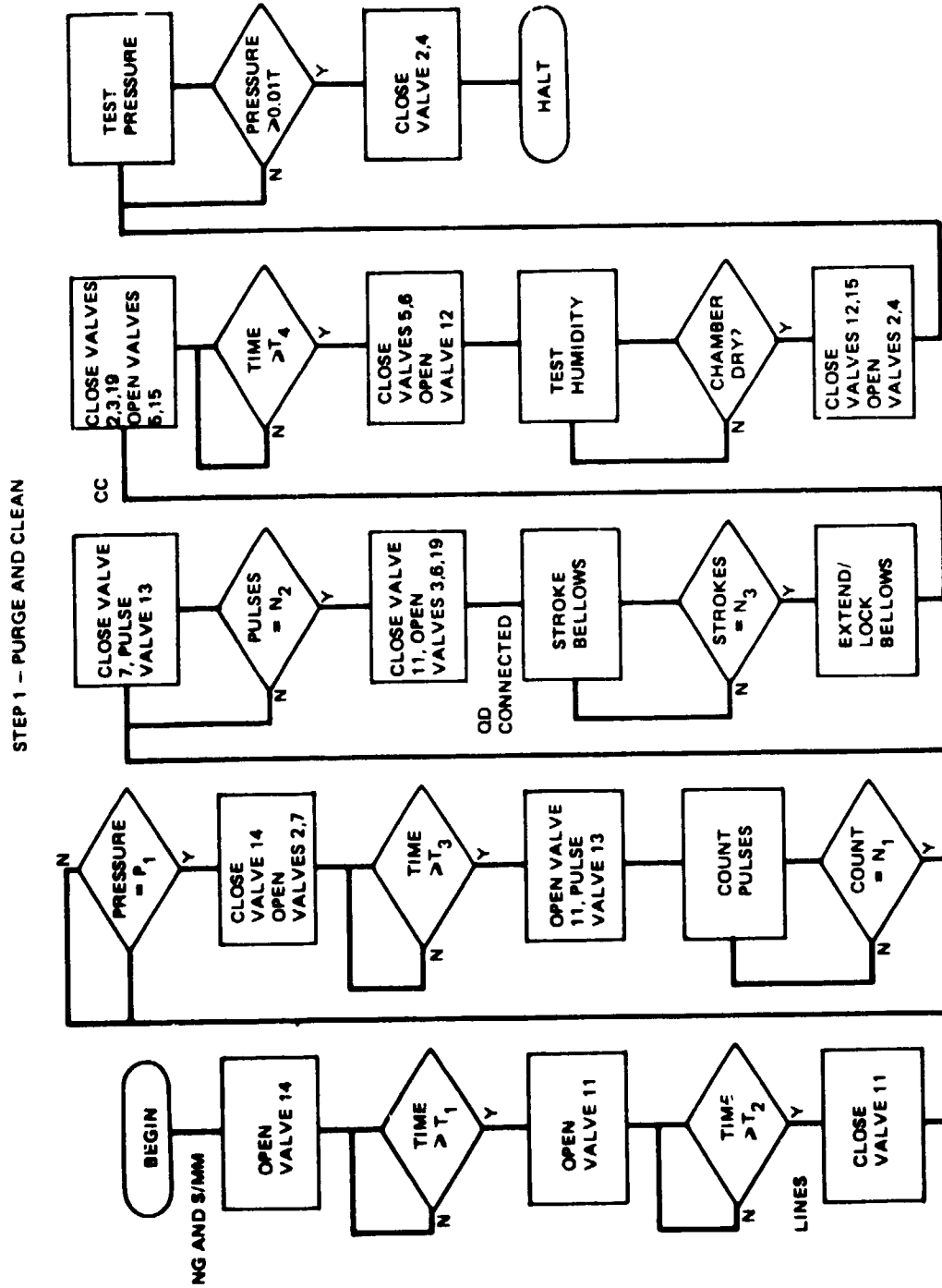
Figure 10-15. Aerosol Generation Flow (Sheet 1 of 3)
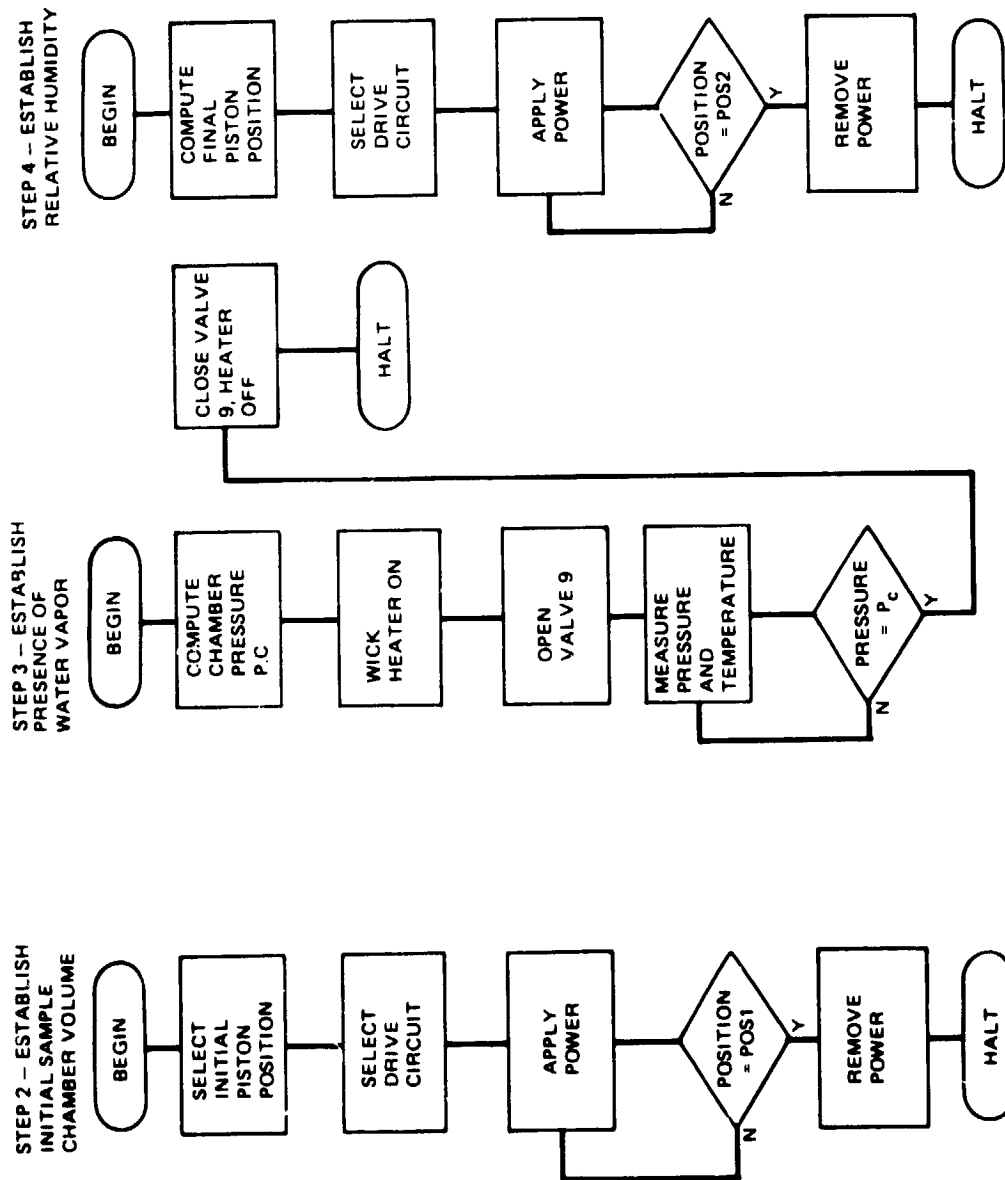
Figure 10-15. Aerosol Generation Flow (Sheet 2 of 3)
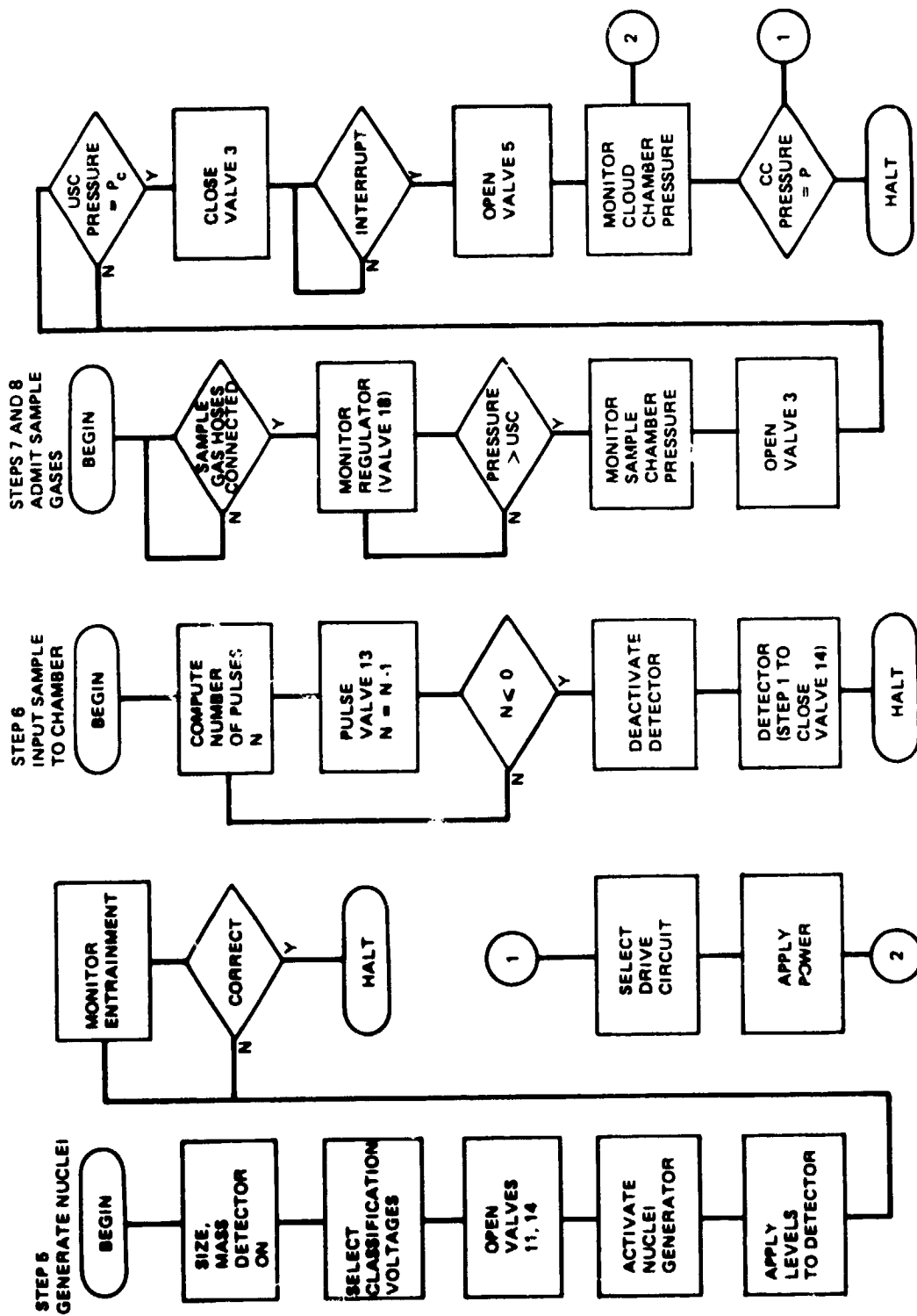
Figure 10-15. Aerosol Generation Flow (Sheet 3 of 3)
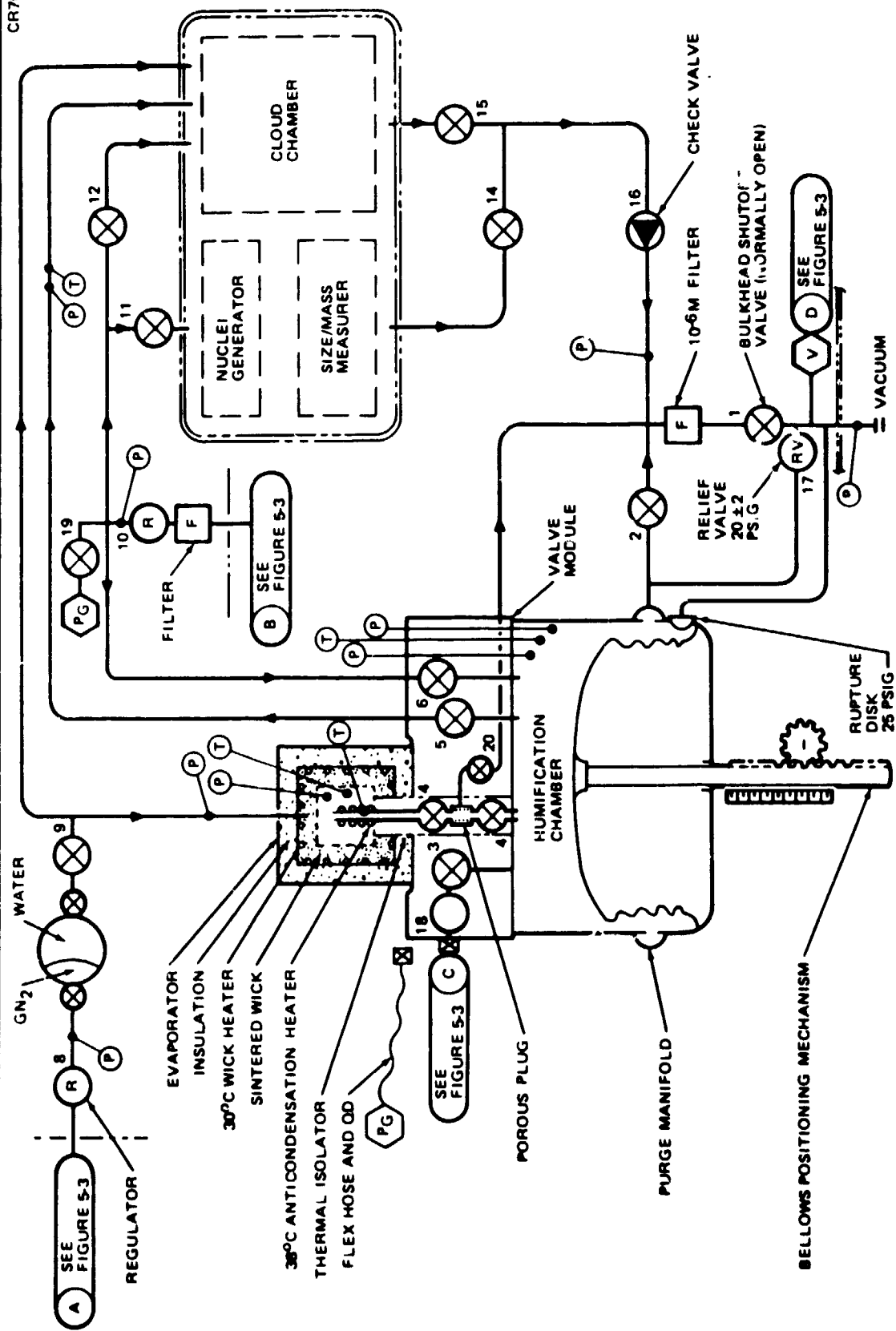
Figure 10-16. Flow, Humidity, and Pressure Control

CR76

ment program. Sizing for chamber operations is therefore tentative and additional flows will be required if a "bottom-up" approach is to be followed. The aerosol generation flow was found to be representative as the "preparation of nuclei" flow for this experiment and required only minor changes in step 3 and the elimination of step 4 (Figure 10-15). Approximately 70 unique operations (equivalent to 210 instructions by our previous measure) were found to be required exclusive of recorder and camera control requirements which, by our previous allocations, would be performed by the Spacelab system. Data base requirements are again approximately 40 words such that the total experiment requirements could be met with a 1,000-word memory. Assuming two uniquely programmed runs per day for 5 days at 500 words per program plus 500 words for aerosol preparation yields a total memory requirement of 5,500 words. With sharing of subroutines, this total should be reducible to 2,000 words.

Estimates of software requirements for display and control to be performed by the Spacelab complex, while possible to develop, were not accomplished due to the realization that graphic display formats, limit check routines, and conversion of voltage levels to engineering units will all be existing software modules offered as part of Spacelab services. Programming of the computer will also be performed in a higher order language (HOL) such that the number of machine instructions may be three to five times the HOL instructions. However, based upon the quantity of status measurements available for checkout, a program containing a data base of 210 words (3 x 70) and as few as 20 HOL instructions should suffice.

10.4.3 Command

Assessment of the data rates and quantities associated with the command system is related to the performance of the following types of functions:

A. Redirect the performance of a particular task which has not been executed within the constraints of the ongoing experiment requirements.

B. Update the stored program sequence to include cases not originally programmed but which are of new interest due to unanticipated results of the preceding test series.

C. Update the stored program sequence to perform a different set of experiments due to the inability to perform the original planned series because of equipment malfunctions.

D. Initiate the next step in the performance of a particular experiment after determining via telemetry that the preceding constraints have been achieved.

E. Interrupt an ongoing sequence whose continuance would be useless.

The number of data bits required to perform the above functions varies from about 32 bits to approximately 16 kilobits depending upon the specific function to be accomplished. For a simple function like item D or E, a single 32-bit data word would suffice. For the more complex functions like items A through C, up to about 500 32-bit words (16 kilobits of data) would be required.

The baseline capability of the orbiter uplink command system (into the Space-lab) through both the STDN and TDRS communication systems is 2 kbps. With the near-continuous contact times available through the TDRS, functions like items A, D, and E could be performed with essentially no impact on the oper-ation of the system. The performance of functions like items C and D could be accomplished through either the TDRS or STDN and would require approxi-mately 8 seconds of transmission time (16 kilobits divided by 2 kbps). This also presents an insignificant impact on the operation of the command system since a 16-kilobit data burst could program operation of the CPL for the full duration of a normal Spacelab mission.

10.4.4 Controls

A control system will be required to perform the following types of functions within the CPL:

A. The time-sequenced operation of valves in the CPL to control the flow of gases, liquids, and particles through, into, or out of various components of the CPL.

B. The time-sequenced operation of devices required to control and monitor experimental conditions and results.

C. The parameter-level-controlled operation of equipment to achieve or maintain environmental or operational conditions under which an ongoing experiment is to be performed.

D. The parameter-time-profiled operation of equipment to achieve a time-varying condition under which an ongoing experiment is to be performed.

A review of the preliminary definition of the CPL design shows that approximately 40 valves may be utilized to control the flow of gases, etc., through the CPL.

Included in the category of devices requiring time sequencing are such things as heaters, lights, cameras, meters, and recorders. Approximately 15 devices will require time sequencing to permit efficient control and monitoring of experiment conditions and results. An initial list of items in this control category (Item B above) is presented in Table 10-3.

A review of the preliminary operational procedures indicates that time-sequencing requirements of commands for operation of valves and devices wi'l vary from once per experimental run to tens of commands per sequence involving one or more of the valves or devices. Therefore, a command system capable of outputting approximately 110 discretes (on/off) commands (2 states x [40 valves + 15 devices]) will be required by the CPL. The command rate capability for these commands should be on the order of 40 commands per second (10 cycles/second x 2 commands/cycle x 2 channels simultaneously).

A number of control operations involving the use of analog functions have been identified in the preliminary design of the CPL. These operations may be manually performed or automated depending upon the nature and requirement of the experiment to be performed. In general, the control requirements involving analog control functions fall into the two categories identified as item C or D, above; that is, parameter level control or parameter time profile control. In the former case either a direct input analog (level set) command is required or a feedback input analog (comparator) command is required to achieve or maintain the environmental or operational conditions under which the ongoing experiment is to be performed. The latter type (time profiled, analog command function) requires that a command input vary continuously either directly as a function of time or indirectly (via feedback) to create a condition which varies in accordance with some preplanned time profile of the condition.

Table 10-3

CPL ANALOG CONTROL FUNCTIONS

Item	Component	Function	Level	Profile
				Type
1	Cloud chamber	Upper plate temperature control	X	X
2	Cloud chamber	Lower plate temperature control	X	X
3	Electric field generator	Field intensity control	X	
4	Electric field generator	Field frequency control	X	
5	Motion controller	X axis drive	X	X
6	Motion controller	Y axis drive	X	X
7	Motion controller	Z axis drive	X	X
8	Droplet Generator	Generator frequency control	X	
9	Expansion chamber	Bellows position control	X	?
10	Humidity controller	Chamber humidity control	X	
11	Universal sample chamber	Bellows position control	X	
12	Acoustic motion control	X axis drive		X
13	Acoustic motion control	Y axis drive		X
14	Acoustic motion control	Z axis drive		X
15	TV camera	Zoom control	X	
16	Film camera	Zoom control	X	

Table 10-3 contains a list of identified functions which may require analog input commands for operation of the CPL. It is estimated that the commands will all be low-frequency commands on the order of several cycles per second. With the highest frequency being that required for operation of the positioning control system in support of experiment class 20 (unventilated droplets). This class experiment requires an analog command input of approximately 10 Hz to maintain particle motion along a 0.02-meter-radius path at a velocity of 0.15 meters/second. Since the motion control devices (acoustical and electric field) are envisioned as three-axis control devices, it may be necessary to input simultaneously to all three axes for the desired particle path. This results in an analog command generation requirement of 150 samples per second (3 channels x 10 Hz/channel x 5 sample/Hz).

The assessment of the devices in the CPL which may require automated analog command inputs indicate that the CPL command system should contain approximately 20 analog command channels whose frequency output capability is 10 Hz minimum.

In summary, the data rate and quantity requirement for the CPL command system is as follows:

Type	Quantity (Channels)	Rate (Command/Second)
Discrete	110	40
An-log	20	150
Total	130	190

10.4.5 Data Transfer

As a result of the small quantity of measurements and low sample rates, data transfer within the laboratory is not a particular problem in itself; i.e. less than 1 percent of the Spacelab's capability is being used. A similar situation prevails in the case of the downlinks in that no transfer of digital and video data is absolutely necessary although additional video tape reels would be required should data be stored. It is also probable that the principal investigators will want to observe experiment results on a daily basis and/or compare the on-orbit data to that developed in parallel ground experiments.

Since only two recorders will be available in the Spacelab, any recorded "dump" of data would require interrupting an in-progress experiment. Since such a practice would be undesirable if not impossible without destroying the experimental samples, recorded data transfer to the ground should await experiment completion. Based upon the recorder analysis, a digital rate of 16 kbps would be used. A video rate of 5 MHz may also be assumed although STDN remote site recorders are limited to a bandwidth of 4.2 MHz at former MSFC stations.

Real-time digital data transfer would be at the generation rate of 1 kbps with provisions for one accompanying voice channel at 32 kbps. With the availability of a new-continuous (85 percent of the time) 25-kbps telemetry downlink in addition to the voice link, there seems to be little need for transfer of taped digital data. The primary reasons for recording would be to: (1) use the link efficiently; (2) preserve all the data; (3) preserve the data in case of communication dropouts; and (4) allow playback of data at experiment completion for analysis. Real-time transfer of video data, as desired, is also feasible over the 50 Mbps or 5-MHz TDRS channel. Comments (1), (3), and (4) apply.

Use of the STDN channels is possible and links are provided. In the period of the 1980's when the CPL is due to fly, the primary data transfer support facility for low-earth-orbit payloads will be the TDRSS. The remote STDN sites are expected to be reduced in number from the present 15 to 7 or 8 and used to support high- and medium-altitude spacecraft.

Table 10-4 summarizes the downlink data transfer operations. Transfer of real-time data is limited to 20 hours by loss of TDRS line of sight. Recorded data transfer is reduced to 14 to allow completion of 10 hours of experimentation and thus reduced by 15 percent to 12 hours. The command uplink for payloads is established at 2 kbps by the NASA.

10.1.6 Caution and Warning

An analysis of potentially hazardous conditions existing in the CPL was performed. It produced an initial list of seven measurements for monitoring tank and line pressures. In subsequent evaluations, it was concluded that

Table 10-4

DOWNLINK DATA TRANSFER

Data Type	Real Time			Recorded		
Data Form	Voice	Video	Digital	Video	Digital	Voice
Rate Bandwidth	32 kbps	5 MHz	1 kbps	5 MHz	15 kbps	32 kbps
Transfer Time	20 hr	20 hr	20 hr	12 hr	12 hr	12 hr
Period		Any			Following experiment	

there were no factors causing overpressure to occur in five of the seven cases and redesign of the system eliminated the remaining two hazards. As a result, only the basic caution and warning measurements provided by the laboratory are required. Should continuing CPL analysis or the addition of new equipment warrant it, the laboratory system will provide all requisite comparison and annunciator provisions. Remaining to be supplied by the user are the transducers or circuit outputs and whatever signal conditioning is needed to provide compatibility with the C&W system interface.

10.4.7 Information Transfer Internal to the Laboratory

Many types of information must be supplied to the experiment operator on-orbit in order to successfully conduct the cloud physics experiment program. Table 10-5 presents a sample listing. The means by which the information is made available to the operator and the facilities presently available were reviewed in order to ascertain where and how the transfer facilities must be augmented. Four major transfer paths are involved: (1) orbiter-to-Spacelab console, (2) Spacelab console to CPL console, (3) experiment subsystems to CPL console, and (4) experiment subsystems to Spacelab console.

The first of these, orbiter-to-Spacelab console, is well established. Information such as time-of-day, guidance, and navigation functions and uplink information are accommodated and require no CPL augmentation. The Spacelab console to CPL console interface is required to transfer almost every item listed in Table 10-5, exceptions being event time and event sequencing. Two options are available to implement the interface. The

Table 10-5

INFORMATION TRANSFERRED INTERNAL TO THE LABORATORY

1. Time of Day

   - Tape annotation
   - Film annotation
   - Start/end time

2. Event Time

   - Begin sequence
   - End sequence
   - Sequence duration

3. Equipment Status

   - Equipment calibrated
   - Equipment ready (initialized)
   - Control settings

4. Experiment Procedures

   - Crew/equipment run preparation
   - Automatic sequences
   - Manual operations

5. Resource Consumption

   - Tape remaining
   - Film remaining
   - Gas consumption
   - Water consumption

6. Experiment Progress

   - Sequence of events
   - Video (visual) monitor
   - Primary measurements (aerosol size and quantity, dew point, relative humidity)

7. Experiment Program Revisions

   - Procedure received from the ground
   - Operator parameter/limit changes

8. Checkout (Malfunction) Data

   - Operational confirmation
   - Equipment fault (measurement name, number)
   - Adjacent affected measurements
   - Troubleshooting procedures and recovery options

Spacelab console can incorporate provisions for supplemental parallel keyboard and display drives or information in digital form may be transferred via data bus modems and distribution logic to the CPL console. With the exception of the equipment within the orbiter, parallel drives are not available in the existing design. Documentation has indicated that digital information can be transferred by data bus through remote acquisition units (RAU). Since the purpose of these units is to acquire multiple analog signals and issue commands, only the bus interface and addressing portion of their circuitry appears to be particularly well suited to information transfer.

The data bus distribution hardware and software option would require the expenditure of CPL funds for a capability that should exist in the Spacelab. Other experiments will undoubtedly require remote displays and computer access. On the other hand, supplemental outputs, if incorporated in the design phase, would have little effect on overall equipment cost. Should provisions not be included in the design for this feature, it is possible the NASA would provide a data bus modem as an optional piece of equipment.

For the experiment of CPL console interface, the options are for CPL data acquisition unit or use of an RAU for multiplexing input signals. The selected channels for experiment control would then be provided via a computer-to-controller link. The drawback to this scheme is that the whole premise of providing the controller as CPL equipment would be negated, i.e., a Spacelab system simulator would be required during CPL development. Since the data acquisition unit should cost less than $50,000, it is recommended as the previous trade section indicated.

The last interface, experiment subsystems to laboratory console would be provided by the data acquisition unit. No increase in cost should result from the addition of this interface.

10.4.8 Data Dissemination

In the past, digital data received at remote sites has been processed to extract the desired data channels from telemetry frames or to compress the data by redundancy removal prior to its transfer to GSFC and its subsequent

routing to Houston and MSFC. TV video has been transferred directly from remote sites via leased lines to MCC-Houston. Tapes and hard copy have been returned to Houston prior to dissemination of copies to PI's or secondary data recipients who have submitted data request forms.

The post-1978 network will be reduced from 15 to 7 or 8 remote STDN sites and a TDRSS ground station, with the former primarily serving medium- and high-altitude payloads while the latter supports low-altitude payloads such as the Spacelab. The network digital communications rate from the TDRSS ground terminal will be 56 kbps to 1.344 Mbps or higher as required.

With the exception of the use of the TDRSS ground station at White Sands, operations to disseminate data to the user are not expected to materially change from that shown in Figure 10-17. The CPL data may be expected to be received multiplexed with other laboratory data. During and after reception at the ground station, selected channels would be stripped out (although hardly necessary at the low CPL data rate) and transferred to Houston via GSFC. Digital demultiplexing would then be performed for display or printout of real-time data. After separation of CPL data from the bit streams, tapes could be made available to the requesting user. Complete data tapes recorded at the ground site would be mailed or flown to Houston for extraction of desired CPL data and copies made available in a similar manner.

Video data in real time could be transferred to Houston on leased lines while delayed video tapes would be handled in the same fashion as digital tapes. Tapes recovered from the laboratory would be flown to Houston for copying and handover to the user.

10.4.9 Data Formats

Data are provided in a variety of forms to a number of users and each generally requires a unique format. Formats are required for time multiplexing analog and serial digital data, identifying frames of film annotating tape recordings, graphic CRT displays, etc. Formats must even be provided for such mundane activities as labeling tape and film canisters. The information contained in most of the formats simply identifies the time the
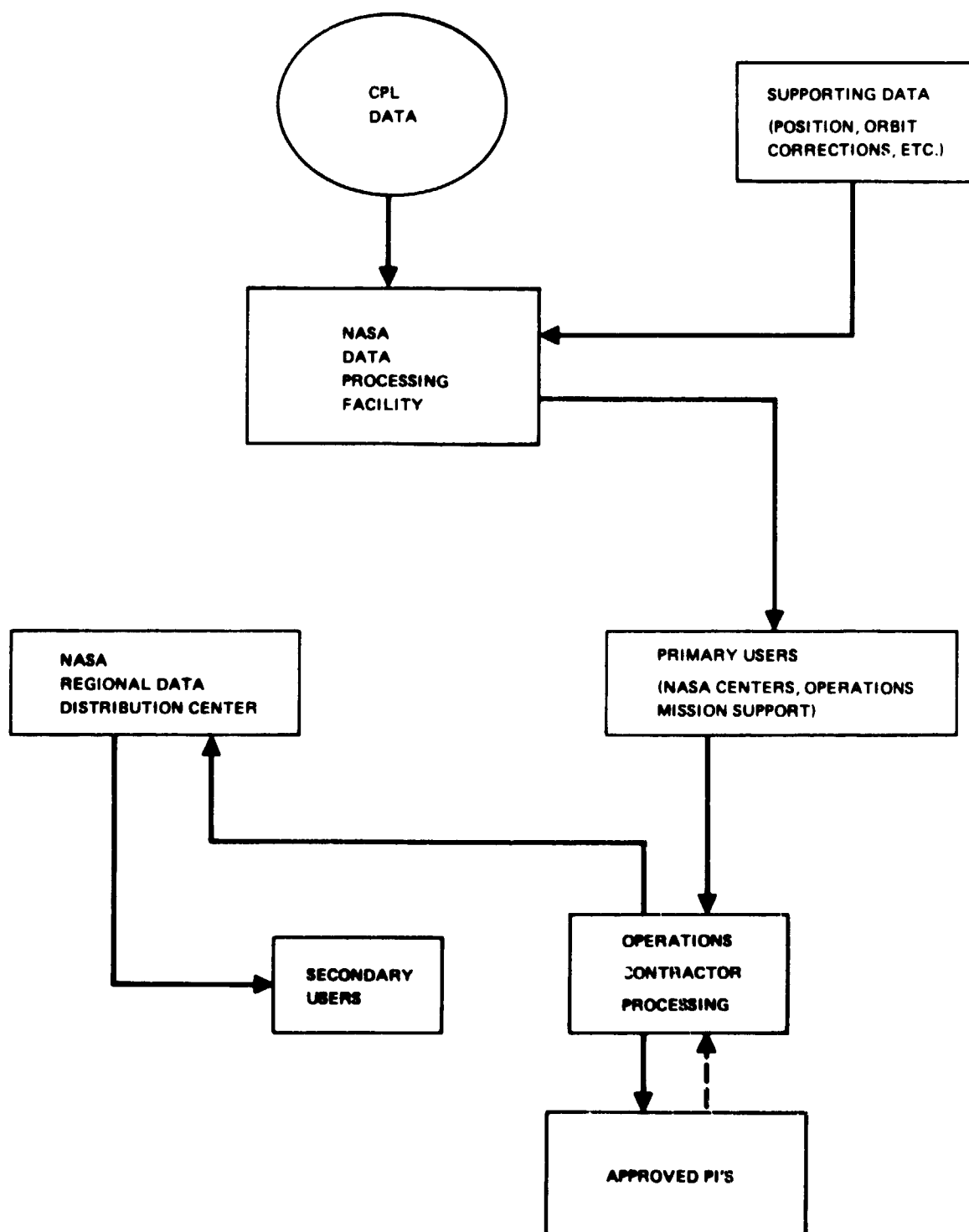
Figure 10-17. Regional Data Flow

data was obtained, the particular activity involved, and other clarifying details which serve to separate the particular activity or sample from others of a similar nature.

Fixed formats for data time multiplexing are somewhat more complex. They produce synchronous data streams by assigning a particular time slot to each word allowing its identification with a single synchronizing word at the beginning of each group or frame. Asynchronous data, occurring when the timing relationship is not fixed, require an address or identifier for each word. Transfer of measurement values only when a change in level occurs results in such data.

Tradeoffs established that the CPL would include a formatter providing a synchronous data stream for control, checkout, and recording. Figure 10-18 illustrates a tentative format which accommodates channel requirements with some capacity for growth. Since an off-the-shelf unit would actually be selected to perform the acquisition function, the fixed formats available in the machine would actually be used. However, the example does provide sizing data and an indication of the units simplicity.

The prime frame has been divided into 64 time slots and a frame rate of one frame per second selected. Forty of the time slots are supercommutated to produce four channels (A1 to A4) sampled 10 times per second. Eight time slots (B12 to B19) are subcommutated to provide 80 channels sampled 0.10 time per second and one time slot (B20) is sub-subcommutated to provide 100 channels sampled 0.01 time per second. The remaining 11 channels (B1 to B11) are sampled one time each second. The format accommodates all present channel requirements (99) at the requisite rates while also providing additional lower rate channels for a total of 195. A field (all channels sampled) is completed in 100 prime frames and, at 10 bits per sample to provide the required conversion accuracy, a data rate of 640 bps results.

Graphic displays also require a more complex form of formatting. The first format which must be provided is a menu which points to the programs resident in memory and allows their callup; each would, perhaps, have its own unique format for data presentation. As a minimum, the CPL will require the

SPECIFICATIONS

WORD RATE	:	64 W/SEC
FRAME RATE	:	1 FR/SEC
SYNC WORD	:	40 BITS
SUBFRAME	:	10 PRIME FRAMES
FIELD	:	100 PRIME FRAMES
BIT RATE	:	640 BPS

REQUIRED:

4 CHANNELS AT 10 SPS
7 CHANNELS AT 1 SPS
55 CHANNELS AT 0.1 SPS
4 CHANNELS AT 0.05 SPS
7 CHANNELS AT 0.03 SPS
14 CHANNELS AT 0.01 SPS
3 CHANNELS UNDEFINED

PROVIDED:

4 SYNC WORD TIME CLOTS
4 CHANNELS AT 10 SPS (A_1-A_4)
11 CHANNELS AT 1 SPS (B_1-B_{11})
80 CHANNELS / : 0.1 SPS $(B_{12}-B_{19})$
100 CHANNELS AT 0.01 SPS (B_{20})

TOTAL CHANNELS REQUIRED: 90

TOTAL CHANNELS PROVIDED: 195

Figure 10-18. Prime Frame Format

presentation of the daily schedule of experiments, the procedure to be followed, checkout fail, and trend data showing resource consumption. Figure 10-19 illustrates typical formats which may be employed. In actual practice, it is expected that the Spacelab will have these formats available in bulk memory; i.e., no special development for the CPL should be necessary.

DIAGNOSTIC

TRANSFER
SYSTEM

TANK — VALVE P_2 — ORIFICE

VALVE P_1

P =
T =
F =

P =

P =

$\Delta P =$

CHECKOUT
TRANSFER SYSTEM

NO.	NAME	LIMITS	VALUE
P_5	CHAMBER	HI 43 / Lo 35	40
P_{10}	LINE	HI 600 / Lo 650	627
P_{13}	DELTA	HI 4 / Lo 2	45

MENU
PROGRAM SELECTION

SCHEDULES	ENTRY
DAY 1	441
DAY 2	442
DAY 3	443
DAY 4	444
DAY 5	445

CHECKOUT	
CONTROL	521
AEROSOL GENERATOR	522
PARTICLE COUNTER	523
GAS SYSTEM	524

PROCEDURE
PURGE SYSTEM NOTES

BEGIN

OPEN VALVE 1 — ENTER 1 3 2 1

PULSE VALVE 2 — ENTER 2 4 3 1

P = 5

CLOSE VALVE 1 — ENTER 1 3 2 2

TREND DATA

NITROGEN CONSUMPTION

POUNDS

3,000
2,000
1,000

0 1 2 3 4 5 DAY

SCHEDULE
DAY 1

TIME	EXPERIMENT
07:30	ICE NUCLEATION RUN1
010:00	ICE NUCLEATION RUN2
01:30	
04:00	

Figure 10-19. Graphic Display Formats

Section 11
CLOUD PHYSICS EXPERIMENT LABORATORY SCHEDULES

11.1 SUMMARY

The schedules prepared in this study comprise the effort defined in the WBS for all phases of the Zero-Gravity Cloud Physics Experiment Laboratory (CPL) project, from definition/preliminary design (Phase B) through desigr., development/operations (Phase C/D). The schedules are structured to be consistent with the WBS, the available program definitions, and ground rules established for the study. Major program and interfacing milestones established in the project schedule are the basis for activity timing and sequence at all levels of schedule development. Schedule timing and estimates are commensurate with the project definitions and the relative level of study effort at this time; and with the understanding that they are for preliminary planning and tradeoff purposes only.

Schedules (Figures 11-1, 11-2, and 11-3) are presented in a format consistent with a Phase A level of effort. They identify hardware, prototypes, models, and early technology suitable for evaluation of design, performance, and production. Components and contract items requiring early development, critical performance, or specialized testing are sequenced in proper relation to higher level requirements. Detail design, development, test, and evaluation of hardware, software, and procedures are indicated as well as supporting equipment, systems engineering, and integration and project management needed to complete the program documentation.

Three major activities are required to achieve the schedules: (1) a supporting research and technology program in direct support of the CPL concept; (2) a combined design, development, and operational phase (C/D); and (3) the development of cloud physics experiments in essentially the same period and in parallel with the CPL project.
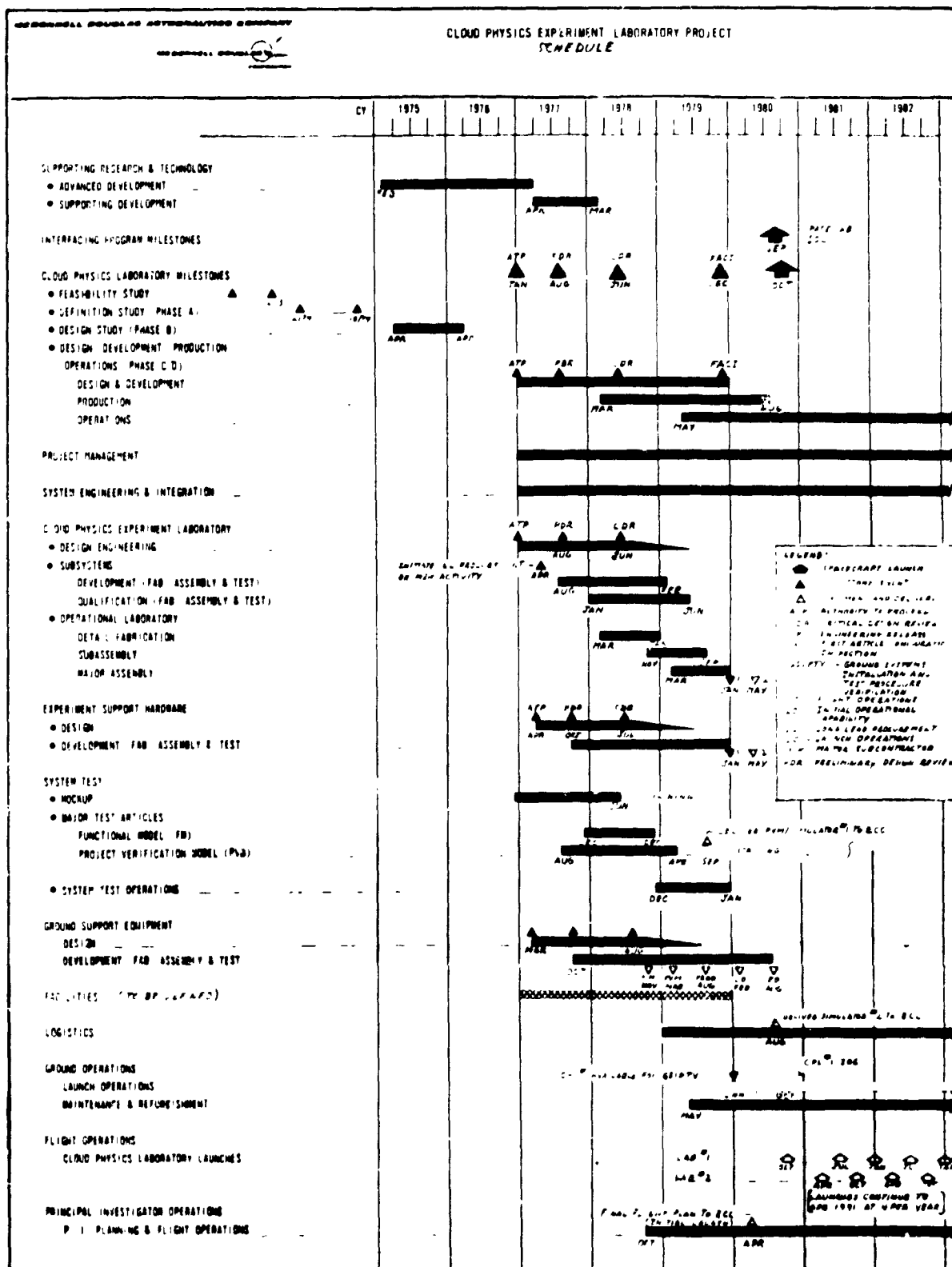
Figure 11-1. Cloud Physics Experiment Laboratory Project Schedule
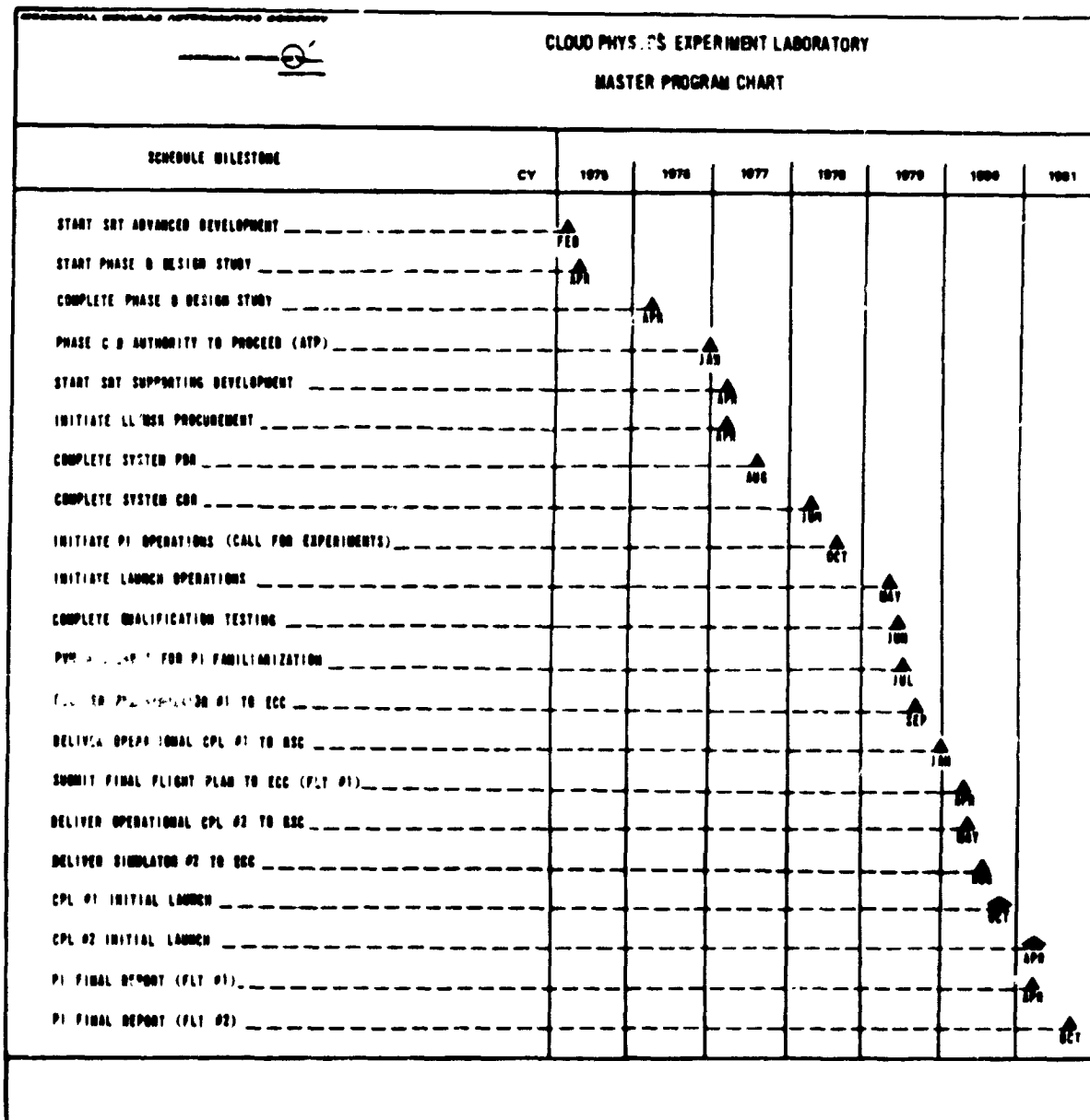
Figure 11-2. Cloud Physics Experiment Laboratory Master Program Chart
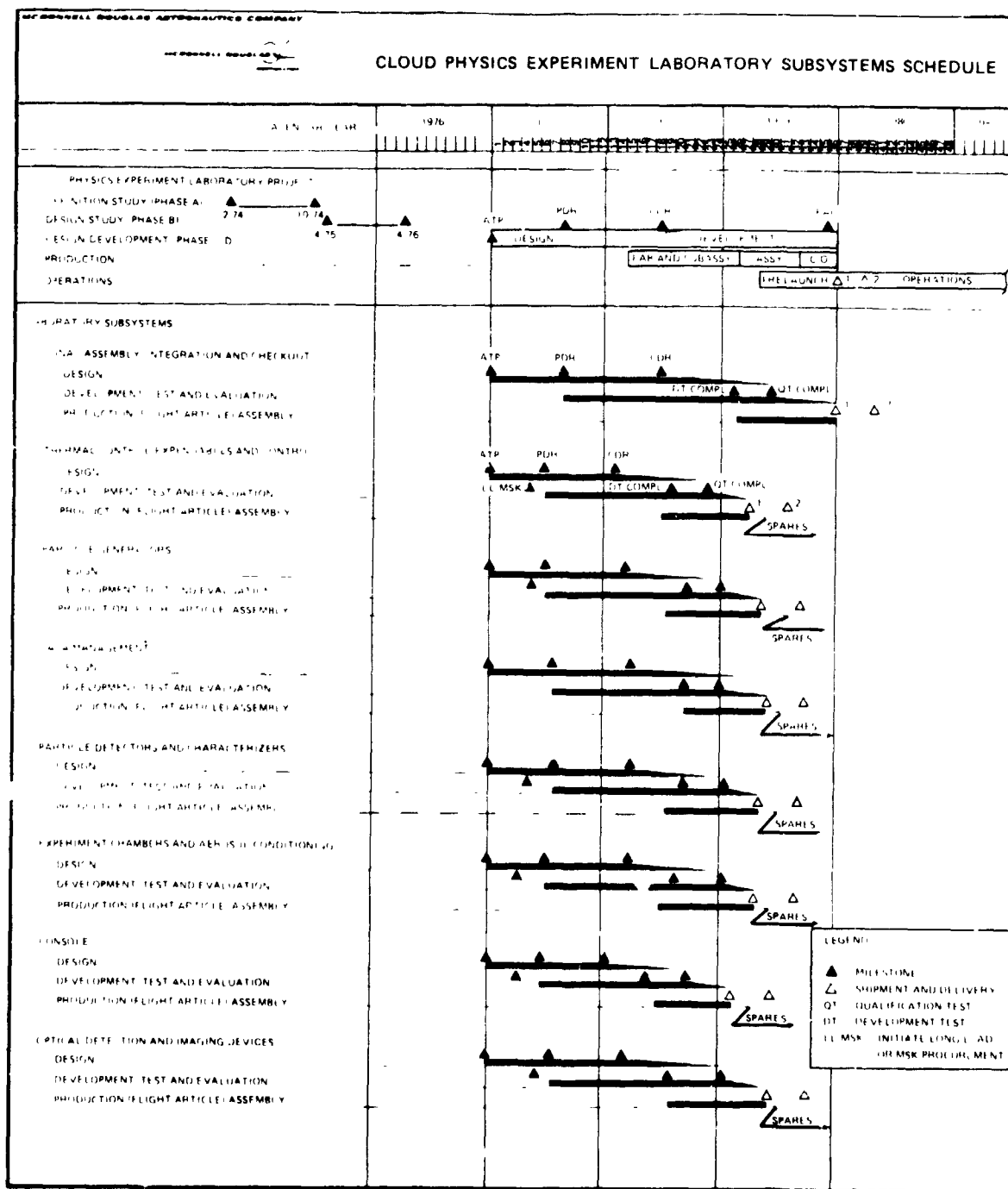
Figure 11-3. Cloud Physics Experiment Laboratory Subsystems Schedule

Time-phasing with the SRT program must be established coincident with requirements for definition, design and development of the CPL project systems. Advanced Development will contribute to the early Phase C/D and must be completed in the early aesign period to prevent schedule impact. Supporting Development activity decision action will occur several months before final engineering design is complete.

11.2 SCHEDULE GUIDELINES

The ground rules established to provide reasonable boundaries within which to define the project schedules are:

    A. Begin to conduct Cloud Physics Experiment Missions 02 October 1980.

    B. Deliver first CPL Operational Vehicle (OV) to the launch site 9 months before launch (03 January 1980).

    C. Consider experiment carrier to be Spacelab/Space Transportation System.

    D. Provide for program operations to extend through CY 1991.

    E. Assume Spacelab/STS to become available as required to support CPL launches.

    F. Assume 6 month turnaround time, launch to launch, for the CP.

    G. Assume total system definition is accomplished prior to the start of hardware development.

    H. Provide hardware procurement, fabrication, assembly, and test quantities as noted:

        1. Procure critical material for all requirements on first buy; prototype and production.

        2. Fabricate all parts on one order except as noted below.

        3. Assemble prototype and qualifiable parts at the same time (PVM and qualification test).

        4. Assembly qualifiable parts for OV's following QT assemblies.

        5. Retain FM at MDAC as an engineering model for future changes.

        6. Usable subsystem portions left after Development Testing are sent to FM.

        7. Usable subsystem portions left after Qualification Testing (75 percent) are sent to the PVM (then to simulator).

8. PVM is delivered to ECC for use as a simulator, after factory completion and checkout.

9. A second simulator is assembled from qualification parts following second production unit (See item 7).

10. Spacelab is considered a vendor for purposes of obtaining Spacelab parts for use in the CPL.

The combined Phase C/D will be initiated in January 1977. Phases C and D are addressed as combined; however, they are depicted separately on schedules in order to identify critical key milestones which impact lower level schedules. Early activity in Phase C/D will provide a realistic statement of technological capability, a detailed system design to meet hardware specification requirements and detailed implementation, development and budgetary plans. Several key project milestones are indicated on CPL schedules and must be achieved if project commitments are to be met.

11.3 PROJECT SCHEDULE FACTORS

Test philosophy activity has identified the CPL test articles to be utilized in the ground test program for integration activities and multiple system testing. Subsystem and system integration testing and software development will be performed on two major test articles, one of which is referred to as the Functional Model (FM) and the other as the Project Verification Model (PVM). The planning is organized to limit the models to a minimum number and yet satisfy the development and operational requirements. An example of this is the utilization of the PVM for (1) manufacturing development and tool fabrication; (2) factory system integration testing, software development, and operating procedure development; (3) training and mission planning; and (4) integration of experiments and checkout of CPL modifications for update installation. Development of the GSE is accomplished in connection with development of the FM and PVM.

The FM is a development tool that is functionally equivalent to an operational vehicle but in a rack-and-panel type assembly. The FM utilizes qualifiable

type, prototype, flight equivalent, and simulated aerospace vehicle equipment (AVE). The major objective of the FM is to perform interface development testing among AVE subsystem and between AVE subsystems and GSE in preparation for support of the system level integration and development testing. The FM will be maintained at the factory as a development tool for interface verification of later requirements for update installation.

The initial use of the PVM is to provide a check of the physical compatibility of subsystem design configurations early in their development. Non-operational subsystems are used for manufacturing development and tool fabrication. The primary objectives are:

    A.   To verify manufacturing methods.

    B.   To check assembly procedures.

    C.   To assist in determining tooling requirements.

    D.   To establish control line and cable routing.

    E.   To establish electrical wire harness routing.

    F.   To verify component accessibility.

    G.   To develop and verify maintenance procedures.

    H.   To facilitate design change feedback.

    I.   To serve as an additional man system procedure definition tool.

    J.   To verify mechanical clearances.

Some time prior to completion of tool fabrication, flight equivalent subsystems will be utilized in the PVM. From this time forward and prior to CPL launch, the PVM includes people, procedures, facilities and production equipment and is used to verify development completion of the CPL at the factory and at KSC. At the factory, the PVM will be used for system integration testing, software development and operating procedure development. This model will be produced in the same factory manufacturing and testing facilities where the operational vehicle is produced. Following manufacturing and checkout at the factory, the PVM will be delivered to ECC. This model will be used for training and mission planning purposes as well as installation of experiments and checkout of CPL modifications for update installation.

Mockups are relatively inexpensive development tools which prove invaluable in early verification of many facets of the design. The installation mockup, which will be updated from the Phase C activity, will be maintained to reflect the current design as the design progresses toward the operational phase. The mockup will be used as a development tool for optimizing man/system interface relationships.

Preliminary schedule planning indicates a need for one set of GSE for the FM, one set of GSE for the PVM, which will be utilized at the factory and shipped with the unit for support of mission integrator activity, and two sets of operational CPL GSE. One operational set is to be used at the factory and shipped to the launch facility with the first operational CPL. An additional set is required at the factory to support production and acceptance te 'ing of the second operational CPL and the CPL simulator. This second set is then delivered with the simulator and is available as a backup at ECC or the launch site.

In addition to test article and operational GSE there will be experiment, launch and flight operations GSE. Launch operations GSE is required to support the CPL or experiments during preparation and launch at the launch facility. Flight operations GSE includes any specialized equipment required for flight operations, communications and command and control of the CPL and installed experiments.

Launch operations will begin with receipt of the CPL and GSE at the launch site approximately 9 months before launch. CPL checkout, CPL/Spacelab interface verification, and complete system checkout will be performed; and final installation of experiments suitable for launch site installation will be completed. Normal integration and system tests will be performed and the CPL launched on board a Spacelab via the Space Transportation System (STS).

11.4 LABORATORY SCHEDULE

The CPL Project Schedule (Figure 11-1) includes the Cloud Physics Laboratory and experiment support equipment. In addition to the flight hardware are the project management, system engineering and integration, system test, ground support equipment, facilities, logistics, ground operations, flight operations and Principal Investigator operations, required to support the design, development, launch and mission operations of the CPL.

A schedule for each of the CPL project areas is presented in Figure 11-1. These schedules identify the project 1 laboratory level requirements and the activities required. The schedules show major milestones and key events related to each area. The master program chart, Figure 11-2, presents the major milestones from initiation of SRT-advanced development through completion of Flight 2 Principal Integration final report.

11.4.1 Supporting Research and Technology (SRT)

Advanced Development

The activities normally start during the definition phase (Phase B), but in some selected cases may start some months prior to this time and extend into the design phase (Phase C). The prime concern is to firm up the performance requirement specification prior to the start of development.

Supporting Development

The activities lead to the development of backup or alternate subsystem and/or components. The effort should be concurrent with the major development effort during the design phase (Phase C).

11.4.2 Interfacing Milestones

These activity milestones are taken from information furnished by the customer and/or participating interfacing program contractors.

11.4.3 Cloud Physics Laboratory Milestones

A. ATP - Authority to Proceed - customer-directed date.

B. CDR - Critical Design Reviews are formal technical reviews of the design of a contract end item. This effort should be accomplished

when the design is essentially complete to formally establish a basis for release of contract end item design and supporting activities for manufacture.

C. FACI - First Article Configuration Inspection is a formal technical review to establish the similarity between the manufactured hardware and the released engineering and to verify that the vehicle has been proven capable of being used as originally intended through other associated test programs. This effort takes place following manufacturing completion and prior to factory delivery.

D. IOC - Initial Operational Capability - Customer-directed launch date. Launch of the first production vehicle capable of performing the intended mission.

E. PDR - Preliminary Design Review is a formal technical review of the basic design approach for a contract end item. The PDR is accomplished early in the development phase (Phase D) to establish the system compatibility of the design approach.

11.4.4 Project Management

This effort encompasses the planning, scheduling, budgeting, controlling, and directing of project activities. Starting at ATP it is continuous throughout the life of the program.

11.4.5 System Engineering and Integration

Initiated at ATP, the SE&I is the overall analysis and control of the Cloud Physics Laboratory engineering requirements, specifications, drawings, interface compatibility, and integration. The effort is continuous to a varying degree throughout the program.

11.4.6 Cloud Physics Laboratory

11.4.6.1 Design Engineering

The objective of design engineering is the translation of the requirements of the Cloud Physics Laboratory project specifications into the detailed design

of the operational system. Design reviews are required to measure compliance with specific design accomplishments. The effort that was initiated at ATP continues at a relatively even level of effort through CDR, tapering to zero with the release of final installation drawings. All effort following final drawing release is defined as sustaining engineering.

11.4.6.2 Subsystems
Development (Fabrication, Assembly, and Test)
Subsystem development takes place over the period from PDR to the start of final qualification testing to determine and evaluate the design feasibility and to demonstrate that the design meets the specified requirements. Included are the fabrication assembly and integration of test specimens.

Qualification (Fabrication, Assembly, and Test)
Subsystem qualification tests, performed to demonstrate specification compliance, start with the first qualifiable hardware available following critical design review of a specific item. All tests are expected to be complete no later than the mid-point of system test operations taking place on the PVM.

11.4.6.3 Operational Laboratory
Detail Fabrication
Fabrication of CPL production details is initiated with the release of engineering drawings, following CDR, and continues as necessary to support sub and major assembly of the operational laboratory.

Subassembly
Starting with the availability of first production details, subassembly is expected to be complete with the delivery of the final unit midway through major assembly.

Major Assembly
Subsystem installation, integration, factory checkout, and final acceptance are included in major assembly. Activity starts with the availability of the first completed subassemblies, in line with completion of PVM subsystem

installation and integration which provides proven methods and learning developed during the PVM assembly. Activity is complete when the vehicle is delivered to the launch site.

11.4.7 Experiment Support Hardware

11.4.7.1 Design
Design of experiment support hardware lags the design of the CPL by from one to two months to allow for availability of CPL design information effecting the ESH.

11.4.7.2 Development, Fabrication, Assembly, and Test
This activity, although lagging at the start because of design, is approximately in parallel with like events of the operational laboratory and will be complete at the same time.

11.4.8 System Test

11.4.8.1 Mockups
This is a continuing and expanding effort that was started in Phase B. The effort is expected to be 90 percent complete before CDR, followed by only minor activity for new development or change requirements.

11.4.8.2 Major Test Articles
Functional Model
Activity is initiated with the fabrication of racks and installation of breadboard subassemblies, following PDR. Subsystem installation and integration and functional testing is expected to be completed to support the start of test operations on the PVM.

Project Verification Model (PVM)
PVM assembly start is synomymous with the initiation of manufacturing development and tool fabrication. This is just prior to final PDR. PVM activity continues through the installation and integration of subsystems and test operations. Activity completion is timed to coincide with the start of factory checkout on the first production vehicle.

11.4.8.3 System Test Operations

This effort starts with initial test operation of the FM, includes test operation of the PVM, factory checkout of the production vehicle, and is complete with final acceptance test and preparation for delivery.

11.4.9 Ground Support Equipment

11.4.9.1 Design

Ground support equipment design lags CPL design by 2 months to ensure compatibility.

11.4.9.2 Development, Fabrication, Assembly, and Test

Starting at PDR completion, the GSE development cycle continues through the completion of flight operations equipment, 2 months before first CPL launch.

11.4.10 Facilities

No CPL-unique facility requirements have yet been identified. Generally, facilities planning identifies requirements peculiar to the CPL project in Phase B and continues into Phase C to include new facilities, modifications to existing facilities, documentation requirements, and interrelationships with other elements of the national space program. Specifications, A&E design, construction and activation follow in this order. The effort is complete with launch facility modification and reactivation about the time of first flight hardware delivery.

11.4.11 Logistics

Support prelaunch operations, following CPL and GSE Engineering release. Activities are initiated with the establishment of requirements for hardware and software. Logistics support to the CPL project is a continuing effort including Training, Transportation and Handling, and Inventory Control.

11.4.12 Ground Operations

11.4.12.1 Launch Operations
Launch operations comprise the hardware and software activities involved directly in the prelaunch and launch operations at the launch site. This activity is initiated approximately 8 months before first CPL launch with the requirements and procedures identification. Site activation, assembling delivered CPL equipment, servicing, installation of the CPL in the Spacelab, checkout, postflight removal of the CPL, etc., are continuing functions for the life of the program.

11.4.12.2 Maintenance and Refurbishment
This activity takes place in parallel with the launch operations activity to identify the requirements and procedures needed to accomplish this task and to complement that activity. It also is a continuing effort for the life of the program.

11.4.13 Flight Operations for Cloud Physics Laboratory Launches
Flight operations activity of the CPL start with launch of the first operational vehicle and continue in support of each launch and on-orbit operation for the life of the program. This includes the availability of technical personnel in an advisory capacity and the resolution of real-time CPL problems.

11.4.14 Principal Investigator Operations

11.4.14.1 Planning and Flight Operations
This activity, performed by the principal investigator(s), is initiated early in the program to formulate the experiment mission objectives and define the experiment mission laboratory equipment. It is a continuing effort including coordination of astronaut training, formulation of mission timelines, performing in-flight operations, debriefing, data reduction, and preparation of experiment mission reports.

11.4.14.2 Support Equipment

Principal investigator support equipment is unique to Principal investigator requirements not supported by other CPL systems. Design, development, test, and evaluation of this equipment starts early in the program, following the basic CPL requirements definition. The equipment is produced, checked out, and delivered as necessary to support Principal Investigator operations activity but not later than delivery of the first operational CPL to the launch site.

11.5 SUBSYSTEM SCHEDULES

The Cloud Physics Laboratory (CPL) (WBS 3.0) is composed of the following subsystems:

WBS No.	Subsystem
3.1	Final Assembly, Integration and Checkout
3.2	Thermal Control/Expendables and Control
3.3	Particle Generators
3.4	Data Management
3.5	Particle Detectors and Characterizers
3.6	Experiment Chambers and Aerosol Conditioning
3.7	Console
3.8	Optical Detection and Imaging Devices

Figure 11-2 defines the development/production master schedule for the CPL.

The schedules show design, development, test, and manufacturing requirements. CPL subsystem level activities presented include design engineering, subsystem development test qualification test and deliveries and operational vehicle manufacturing require nents.

The composite subsystem development and qualification test time spans are established based on the CPL system level time requirements as constrained by the program phase durations. The individual subsystem development and qualification testing is performed initially during the test time spans allocated. Subsystem integration testing in the functional model (FM) and project verification model (PVM) is then performed at the CPL system level.

A schedule for each of the subsystems is presented in Figure 11-3. These schedules identify subsystem level requirements and development activities required to design, test, and produce the subsystems. The schedules show major milestones, key events, and critical actions related to each subsystem.

Subsystem Design, Development. Test and Evaluation (DDT&E) begins with Phase C/D ATP and ends at qualification test completion. Manufacturing time spans begin with nonoperational units for mockup and PVM and end when manufacturing of production units for spares is complete. Non-operational units are required for mockups and the project verification test article (PVM) during early manufacturing development and tool fabrication. Nonqualification units are required for development test and the functional test model (FM). Qualification units are required for qualification testing, for PVM subsystem assembly, integration and system verification testing, and for the completion of the CPL simulator. Production (flight article) units are supplied for two CPL operational vehicles and to support the spares requirements.

The schedules represent the time-related synthesis of a number of influencing factors, which are discussed in the following paragraphs.

Two non-qualification units are produced for each subsystem. One unit of the console subsystem is shipped directly to the PVM. One unit of each of the other subsystems is used for development testing of the subsystem. The second nonqualification unit of each subsystem is shipped directly to the FM.

Two qualification units are produced for each subsystem. The first unit is used for qualification testing. At the completion of qualification testing the usable portion of the subsystem (75 percent) is shipped to the simulator. An additional 25 percent of an equivalent subsystem is produced and shipped directly to the simulator. Assuming successful qualification test using the first unit, the second qualification unit is shipped directly to the PVM upon completion of manufacture. Additional testing is performed early in the development phase at the component, subassembly and assembly levels.

The CPL subsystems will require unique design, development and test activities. Those systems defined as major problem areas will require extensive investigation, development and qualification Many of the components and assemblies have been employed in other progra ... and are categorized as standard equipment design. However, difficulties relating to modification of commercial and terrestrial laboratory equipment required to withstand launch loads and zero-g environments and development of new equipment, will necessitate detail attention and development verification to assure that all technical requirements are achieved.

The requirement to design, develop, test, and produce the Cloud Physics Laboratory within a 36-month period and the expected long-lead procurement/ major subcontractor delivery of components and subassemblies precludes the use of historical schedule practice in some areas. Schedule compression is reflected in development and qualification test overlaps, minimum assembly and integration time, early initiation of long-lead procurement/major sub-contracts, ATP, and greater dependence on SRT advance development.

The subsystems are composed of many different assemblies that require integration within each other and with the configuration. A diversity of technology is required to develop successful subsystems, including high-pressure gas storage, atmosphere pressure and composition control, vacuum pumping, temperature and humidity control, droplet charge distribution, particle generation, heat transfer and electromechanical control.

There are areas of technical capability in the experiment chambers/aerosol conditioning and the particle generator subsystems that are unique and require special attention during the design and development period. Included is particle generation, particle detection, and chamber wall integration. A development test program to investigate details of design and material use along with persistent attention to detail is required to provide the high reliability to support experiment conclusions.

Key subsystem level problems are: (1) the integration of the many assemblies so that they are compatible with each other, and (2) the integration of these assemblies into the configuration. Many of these assemblies, such as atmosphere temperature control and the heat transfer circuits, are sensitive to the configuration. Therefore, it is vital to complete integrated subsystem level tests before final qualification of assemblies.

An additional 6 months, 42 months from ATP to first production delivery, would benefit the overall project by allowing development, evaluation and qualification to take place in a more timely manner. Development risk would decrease, the schedule confidence level would increase, and the possibility of a reduction in GSE requirements could be better explored. The depth of funding and the success achieved in the SRT development will affect the magnitude of development problems in Phase C/D and assure that the resulting concept is an optimum design.

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Appendix
WORK BREAKDOWN STRUCTURE AND DICTIONARY
FOR
ZERO GRAVITY CLOUD PHYSICS EXPERIMENT LABORATORY
DEFINITION STUDY

A.1 INTRODUCTION

The proposed MDAC Cloud Physics Experiment Laboratory Project Work Breakdown Structure (WBS) Dictionary defines the scope of each item in the WBS. In doing so, it provides a means for locating the proper "home" for functions/tasks as they are identified.

A.2 WORK BREAKDOWN STRUCTURE

The Cloud Physics Experiment WBS is a product-oriented display of both hardware and key functions that define the end product to be developed and produced. The WBS serves as a common framework for Program Definition 'n structuring the technical plan, development schedule, and cost definition.

The Cloud Physics Experiment Laboratory Program will be accomplished in three phases. These phases are described as follows:

A. Design, Development, Test and Evaluation (DDT&E) -- This phase consists of the cost of designing, developing, testing, and evaluating an item. Specifically, it includes such items as the following: Development engineering and development support, major test hardware, captive and ground test, ground support equipment, tooling, special test equipment, and site activation.

B. Production -- This phase is defined as the costs associated with producing flight hardware through acceptance of the hardware by the Government including all costs associated with: (1) the fabrication, assembly, and checkout of flight hardware; (2) ground test and factory checkout of flight hardware; (3) initial spares; and (4) maintenance of tooling and special test equipment.

C. Operation -- This phase is defined as the cost associated with the following activities:

1. Support Operations are defined as (1) replacement spares to support both operational airborne and ground hardware (not GSE), (2) sustaining engineering to support the production of spares and hardware modifications, and (3) maintenance of GSE and spares for GSE.

2. Launch Operations -- The costs for receiving the flight hardware, prelaunch assembly into the Orbiter vehicle, test and checkout, servicing, launching, and post-launch support directly related to the Cloud Physics Laboratory.

3. Mission Operations -- The cost of mission control, mission planning, flight crew training, simulation aids required for crew training (not to include the cost of those items identified elsewhere), and in-flight mission costs directly related to the Cloud Physics Laboratory.

4. Maintenance and Refurbishment Operations -- The cost of activities required to maintain and restore a previously flown reusable system to a flight readiness condition.

The applicability of the various WBS's to these phases is depicted in Table A-1.

EFFECTIVITY OF WBS ELEMENTS

WBS No.	WBS Element	Contract Phase		
		DDT&E	Production	Operations
1.0	Project Management	X	X	X
2.0	System Engineering and Integration	X	X	X
3.0	Cloud Physics Experiment Laboratory			
3.1	Final Assembly Integration and Checkout	X	X	
3.2	Thermal Control/ Expendables Storage and Control	X	X	X
3.3	Particle Generators	X	X	X
3.4	Data Management	X	X	X
3.5	Particle Detectors and Characterizers	X	X	X
3.6	Experiment Chambers and Aerosol Conditioning	X	X	X
3.7	Console	X	X	X
3.8	Optical and Imaging Devices	X	X	X
4.0	Experiment Support Hardware	X	X	X
5.0	System Test	X		
6.0	Ground Support Equipment	X	X	X
7.0	Facilities	X	X	X
8.0	Logistics			
8.1	Training	X		X
8.2	Transportation and Handling	X	X	X
8.3	Inventory Control	X		X
9.0	Ground Operations			
9.1	Recovery Operations			X
9.2	Maintenance/Refurbishment Activities			X
9.3	Checkout Operations and Certification for Flight			X
9.4	Launch Operations			X
10.0	Flight Operations			
10.1	Mission Planning			X
10.2	Flight Control and Evaluation			X

Table A-1 (Sheet 2 of 2)

EFFECTIVITY OF WBS ELEMENTS

WBS No.	WBS Element	Contract Phase		
		DDT&E	Production	Operations
11.0	Principal Investigator Operations			
11.1	PI Planning Operations			X
11.2	PI Preflight Operations			X
11.3	PI Flight/Postflight Operations			X

WBS 0.0 CLOUD PHYSICS EXPERIMENT LABORATORY PROJECT

This summary element contains all labor and material required to design, develop, manufacture, procure, assemble, test, check out and deliver flight Cloud Physics Experiment Laboratory to the Marshall Space Flight Center. Also provided are test articles, mockups, support equipment, training, and flight support activities.

This element is subdivided into:

WBS No.	Title
1.0	Project Management
2.0	System Engineering and Integration
3.0	Cloud Physics Experiment Laboratory
4.0	Experiment Support Hardware
5.0	System Test
6.0	Ground Support Equipment
7.0	Facilities
8.0	Logistics
9.0	Ground Operations
10.0	Flight Operations
11.0	Principal Investigator Operations

WBS 1.0 PROJECT MANAGEMENT

This element contains the effort associated with planning, scheduling, budgeting, controlling, and directing project activities. Also included is the accomplishment of such disciplines as Configuration Management, Performance Management, GFE Management, and Data Management. Customer liaison and contract administration are also performed in this element.

WBS 2.0   SYSTEM ENGINEERING AND INTEGRATION
          Overall system analyses, trade studies, weight analysis and
          weight management, interface control between laboratory sys-
          tems and the scheduling, check, and release of engineering draw-
          ings are performed in this element. Preliminary and final design
          reviews are coordinated and conducted here. Also included are
          the preparation of project-level specifications, establishment of
          test program requirements, cost optimization and safety, relia-
          bility, producibility, and quality analyses. Integration of the
          Cloud Physics Experiment into the Spacelab is included.

          All other integration (i.e., Spacelab with other payloads) is the
          responsibility of others.

WBS 3.0   CLOUD PHYSICS EXPERIMENT LABORATORY
          This summary element contains all the labor and materials
          required to design, develop, manufacture, procure, assemble,
          test, check out, and deliver flight laboratory units and opera-
          tional spare parts. Subsystem and component development and
          qualification tests are conducted. Purchased parts are qualified
          by the suppliers.

          This element is subdivided into:

          WBS No.   Title
            3.1   Final Assembly, Integration and Checkout
            3.2   Thermal Control/Expendables Storage and
                         Control
            3.3   Particle Generators
            3.4   Data Management
            3.5   Particle Detectors and Characterizers
            3.6   Experiment Chambers and Aerosol
                         Conditioning
            3.7   Console
            3.8   Optical and Imaging Devices

WBS 3.1 FINAL ASSEMBLY, INTEGRATION, AND CHECKOUT

This element contains all labor and material required to integrate the various system modules into a viable laboratory. Final assembly, including attachment and installation hardware, final factory acceptance operations, packaging/crating, and sl _____ ' to KSC are included. Also included are the preparatio of final factory acceptance checkout procedures, manufacturing liaison, and the coordination and accomplishment of customer acceptance of the completed articles.

WBS 3.2 THERMAL CONTROL/EXPENDABLES STORAGE AND CONTROL

This summary element contains all labor and material necessary to design, manufacture, procure, assemble, test (development and/or verification), inspect, and check out the thermal control and the storage and control of expendables. Also included are: design and fabrication/purchase of test specimens and operational spares; preparation of engineering drawings, procedures, specifications; supplier qualification and coordination; design and fabrication of tooling, and production planning.

This element is further subdivided into:

WBS No.	Title
3.2.1	Integration, Assembly, and Checkout
3.2.2	Thermal Control
3.2.3	Flow, Humidity, and Pressure Control
3.2.4	Expendables Storage
3.2.5	Instrumentation and Display Subassembly
3.2.6	Expendables
3.2.7	Cleansing Purge and Vent Subassembly

WBS 3.3 PARTICLE GENERATORS

This summary element contains all labor and material necessary to design, manufacture, procure, assemble, test (development and/or verification), inspect, and checkout the particle generators. Also included are: design and fabrication/purchase

of test specimens and operational spares; the preparation of
engineering drawings, procedures, specifications; supplier
qualification and coordination; design and fabrication of tooling;
production planning.

This element is further subdivided into:

WBS No.	Title
3.3.1	Integration, Assembly, and Che kout
3.3.2	Wire Probe Retractor Generator
3.3.3	Water Drop Impeller Generator
3.3.4	Vibrating Orifice Generator
3.3.5	Evaporator/Condenser Generator
3.3.6	Spray Atomizer Generator
3.3.7	Powder Dispersion Generator
3.3.8	Particle Injector and Size Conditioner
3.3.9	Instrumentation/Displays

WBS 3.4   DATA MANAGEMENT

This summary element contains all labor and material necessary
to design, manufacture, procure, assemble, test (development
and/or verification), inspect and check out the data management
subsystem. Also included are: design and fabrication/purchase
of test specimens and operational spares; the preparation of engi-
neering drawings, procedures, and specifications; supplier
qualification and coordination; design and fabrication of tooling;
production planning.

This element is further subdivided into:

WBS No.	Title
3.4.1	Integration, Assembly, and Checkout
3.4.2	Control Processor Assembly
3.4.3	Tape Recorder Assembly*
3.4.4	Master Control Assembly

*Furnished by Spacelab or GFE.

WBS No.	Title
3.4.5	Signal Conditioning Electronics Assembly
3.4.6	Instrumentation and Display Assembly
3.4.7	Expendable..
3.4.8	Cable Assemblies

WBS 3.5   PARTICLE DETECTORS AND CHARACTERIZERS

This summary element contains all labor and material necessary to design, manufacture, procure, assemble, test (development and/or verification), inspect and check out the particle detectors and characterizers subsystem. Also included are: design and fabrication/purchase of test specimens and operational spares; the preparation of engineering drawings, procedures, specifications; supplier qualification and coordination; design and fabrication of tooling; production planning.

This element is further subdivided into:

WBS No.	Title
3.5.1	Integration, Assembly, and Checkout
3.5.2	Optical Particle Counter
3.5.3	Pulse Height Analyzer
3.5.4	Condensation Nucleus Counter
3.5.5	Microporous Filter
3.5.6	Quartz Crystal Mass Monitor
3.5.7	Cascade Impactor
3.5.8	Electrical Aerosol Size Analyzer
3.5.9	Scatterometer
3.5.10	Liquid Water Content Meter
3.5.11	Droplet Size Distribution Meter
3.5.12	Optical Thermoelectric Dew Point Hygrometer
3.5.13	Electric Dew Point Hygrometer
3.5.14	Instrumentation/ Displays

WBS 3.6   EXPERIMENT CHAMBERS AND AEROSOL CONDITIONING

This summary element contains all labor and material necessary to design, manufacture, procure, assemble, test (development and/or verification), inspect and check out the experiment chambers and aerosol conditioning. Also included are: design and fabrication/purchase of test specimens and operational spares; the preparation of engineering drawings, procedures, specifications; supplier qualification and coordination; design and fabrication of tooling; production planning.

This element is further subdivided into:

WBS No.	Title
3.6.1	Integration, Assembly, and Checkout
3.6.2	Static Diffusion Liquid Chamber Assembly
3.6.3	Static Diffusion Ice Chamber Assembly
3.6.4	General Chamber Assembly
3.6.5	Expansion Chamber Assembly
3.6.6	Continuous Flow Diffusion Chamber Assembly
3.6.7	Earth Simulation Chamber Assembly
3.6.8	Nuclei Conditioning Assembly

WBS 3.7   CONSOLE

This summary element contains all labor and material necessary to design, manufacture, procure, assemble, test (development and/or verification), inspect, and check out the console subsystem, including the console support structure and subassembly (mounts, packages, restraints and tools), and power control and distribution assembly. Also included are design and fabrication/purchase of test specimens and operational spares; the preparation of engineering drawings, procedures, specifications; supplier qualification and coordination; design and fabrication of tooling; production planning.

This element is further subdivided into:

WBS No.	Title
3.7.1	Integration, Assembly, and Checkout
3.7.2	Console Support Structure and Subassembly
3.7.3	Power Control and Distribution
*3.7.4	Console Panels and Drawer Subassembly
*3.7.5	Overhead Storage Subassembly
3.7.6	Floor Segment Subassembly
3.7.7	Instrumentation/Displays

WBS 3.8   OPTICAL AND IMAGING DEVICES

This summary element contains all labor and material necessary to design, manufacture, procure, assemble, test (development and/or verification), inspect, and check out the optical and imaging devices subsystem. Also included are: design and fabrication/purchase of test specimens and operational spares; the preparation of engineering drawings. procedures, specifications; supplier qualification and coordination; design and fabrication of tooling; production planning.

This element is further subdivided into:

WBS No.	Title
3.8.1	Integration, Assembly, and Checkout
3.8.2	Cine Camera (35 mm)
3.8.3	Still Camera (35 mm)
3.8.4	Microscope Trinocular
3.8.5	Video Camera Assembly (16 mm)
3.8.6	Light Source
3.8.7	Anenometer
3.8.8	Stereo Microscope
3.8.9	IR Microscope
3.8.10	Support Equipment/Expendables
3.8.11	Displays

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*Note: No need identified. Provided by Spacelab at no cost to CPL.

W BS 4.0   EXPERIMENT SUPPORT HARDWARE

This WBS element is presently for reference only as, to date, no payload-unique support equipment is identified with CPL. If such equipment becomes existent, this element shall contain all labor and material necessary to design, manufacture, procure, assemble, test (development and/or verification), inspect and check out the experiment support hardware. Included are the hardware, equipment (including ancillary equipment) not provided by others (i.e., Spacelab), but which are required for integration of the Cloud Physics Laboratory into the Spacelab and for assurance of proper operation of the Cloud Physics Laboratory after it has been integrated.

W BS 5.0   SYSTEM TEST

In this element are performed the planning, coordination, design, setup, conduct and evaluation of the system-level development and verification tests. Also provided are all effort and materials required to design, build and maintain system-level test articles. Hardware unique to the system-level tests is designed and manufactured or purchased and test procedures are prepared. In a similar manner, hardware and software unique to the mockup are provided.

This element is subdivided into:

WBS No.	Title
5.1	System Test Planning
5.2	Major Test Articles
5.2.1	Mockups
5.2.2	Functional Model
5.2.3	Project Verification Model
5.3	System Development Testing
5.4	System Verification Testing

WBS 6.0   GROUND SUPPORT EQUIPMENT (GSE)

The design, manufacture, procurement, assembly, test, checkout and calibration/maintenance of ground support equipment (GSE) is performed in this WBS element. This equipment is used to handle, service or check out the various laboratory subsystems, either individually or collectively, during factory acceptance checks or launch operations. Included are: design and fabrication/purchase of all hardware; spares; the preparation of engineering drawings, procedures, specifications; manufacturing liaison; supplier qualification and coordination; design and fabrication of tooling; production planning; and any software peculiar to the GSE.

This element is subdivided into:

WBS No.	Title
6.1	GSE Integration
6.2	Electrical GSE
6.3	Mechanical GSE
6.4	Transportation and Handling GSE
6.5	GSE Software

WBS 7.0   FACILITIES

If new facilities, or modifications to existing facilities, are required, they are provided in this WBS element. Included are the planning, coordination, design, fabrication, procurement, inspection, installation, setup, checkout, acceptance, and activation of these facilities. Facility operation and maintenance are provided in this element. Facility operation and maintenance related to manufacturing facilities is a manufacturing cost. Facility operation and maintenance associated with launch and flight operations is an operations cost.

This element encompasses the following subelements:

WBS No.	Title
7.1	Manufacturing Facilities
7.2	Test Facilities
7.3	Launch Facilities

WBS 8.0   LOGISTICS

This WBS summary element contains the effort to implement, operate, and maintain a logistics management for support of the Cloud Physics Laboratory and its related support equipment, including transportation, handling, factory warehousing and inventories, systems orientation and familiarization, training of ground crew personnel, and the design, development and manufacture of those distinctive end-items required specifically to meet the training objectives. Included are operational maintenance trainers, cutaways, and models.

This element is subdivided into:

WBS No.	Title
8.1	Training
8.2	Transportation
8.3	Inventory Control

WBS 8.1   TRAINING

This WBS element contains the effort required to develop training aids to operate, maintain, repair/refurbish, handle, and check out specific Cloud Physics Laboratory mission timelines. Included are the establishment of requirements, the preparation of instructional materials, conduct of classes, maintenance of necessary records. All other training is the responsibility of others, i.e., Spacelab.

This element is subdivided into:

WBS No.	Title
8.1.1	Planning
8.1.2	Training Aids
8.1.3	Conducting Classes

WBS 8.2 **TRANSPORTATION AND HANDLING**

This WBS element refers to the preparation for, and transportation of, major items of equipment and hardware which have special requirements due to their size, weight, shape, or environmental control. Transportation of items not requiring such special considerations is included within the specific vehicle or ground subsystem element. Transportation of the total Cloud Physics Laboratory between manufacturing assembly facility and launch site is included in this element. Special equipment required for handling and transporting the Cloud Physics Laboratory is included under WBS 6.4 - Ground Support Equipment Transportation and Handling.

WBS 8.3 **INVENTORY CONTROL**

This WBS element refers to warehousing and inventory controls of materials, parts, supplies, tooling, equipment, and spares provisioning in support of maintenance and refurbishment of the Cloud Physics Laboratory. Included are costs of inventory control computer software and control system maintenance.

WBS 9.0 **GROUND OPERATIONS**

Within this WBS summary element are provided all activities associated with launch and recovery operations and the maintenance/refurbishment activities of the Cloud Physics Laboratory.

This WBS element is subdivided into:

WBS No.	Title
9.1	Recovery Operations
9.2	Maintenance/Refurbishment Activities
9.3	Checkout Operations and Certification for Flight
9.4	Launch Operations

WBS 9.1   RECOVERY OPERATIONS

This WBS element contains all efforts associated with the planning, coordination, and implementation of recovery activities. Included are such tasks as coordination of schedules, preparation of handling and demating procedures unique to the recovery operations, participation in recovery working groups, liaison and technical representation at recovery site. The overall integration and conduct of recovery operations will not be performed by the CPL project.

WBS 9.2   MAINTENANCE/REFURBISHMENT ACTIVITIES

Maintenance and refurbishment of flight hardware take place in this WBS element. Also included are the coordination activities leading to the establishment of requirements and subsequent procedure preparation and validation, participation in working groups, liaison between the maintenance/refurbishment site and the home plant, postflight inspection of flight hardware. The task of overall coordination and integration of these activities will not be performed by the Cloud Physics Laboratory Project.

WBS 9.3   CHECKOUT OPERATIONS AND CERTIFICATION FOR FLIGHT

This WBS element contains the tasks associated with the checkout and certification for flight of the refurbished CPL. Included are the coordination activities leading to establishment of test criteria, preparation of tests procedures, participation in working groups, and liaison concerning all phases of CPL operations that could impact flight status. The task of overall STS coordination and integration of these activities is greater than, and will not be performed by, the CPL project.

WBS 9.4   LAUNCH OPERATIONS

The efforts to support the launch checkout and integration are included in this WBS element. Included are coordination and implementation of all CPL-related launch activities, coordination of schedules, preparation of handling and checkout criteria

and procedures, participation in launch working groups, liaison between other activities and the launch site, and technical representation at the launch site. The overall integration of pre-launch and launch activities and conduct of the overall STS launch site operations are greater than, and will not be performed by, the CPL project.

WBS 10.0   FLIGHT OPERATIONS
This summary element contains those activities peculiar to flight operational aspects of the laboratory. Overall integration and coordination of these activities are not performed by the Cloud Physics Laboratory Project.

The subdivisions of this WBS element are:

WBS No.	Title
10.1	Mission Planning
10.2	Flight Control and Evaluation

WBS 10.1   MISSION PLANNING
This WBS element contains the activities associated with the establishment of mission requirements, the preparation of in-orbit procedures, the preparation of crew timelines, the coordination of earth-to-orbit communications and data requirements, and participation in mission planning working groups.

WBS 10.2   FLIGHT CONTROL AND EVALUATION
This WBS element includes those activities peculiar to in-flight operation of the Cloud Physics Laboratory. Postflight quick-look evaluation of data and the preparation (i.e., formatting) of postflight reports occur in this element.

Subsystem in-flight performance data for the laboratory will be reduced and evaluated to determine maintenance and refurbishment requirements.

PROGRAM LEVEL 2

PROJECT LEVEL 3

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│   SPACELAB     │
│   PROJECT      │
└ ─ ─ ─ ─ ─ ─ ─ ┘
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SYSTEM LEVEL 4

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┌ ─ ─ ─ ─ ─ ─ ─ ┐          ┌──────────────1.0┐     ┌──────────────┐
│               │          │                 │     │   SYSTEM     │
│   SPACELAB    │          │   PROJECT       │     │ ENGINEERING  │
│               │          │   MANAGEMENT    │     │   AND        │
└ ─ ─ ─ ─ ─ ─ ─ ┘          └─────────────────┘     │ INTEGRATION  │
                                                    └──────────────┘
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SUBSYSTEM LEVEL 5

- STRUCTURAL/MECHANICAL
- ENVIRONMENTAL CONTROL AND
  ATMOSPHERE CONDITIONING
  - ENVIRONMENTAL THERMAL CONTROL
  - LIFE SUPPORT ATMOSPHERE DISTRIBUTION
- CREW SYSTEMS
- DATA MANAGEMENT
- COMMUNICATIONS
- ELECTRIC POWER
  - ELECTRIC DISTRIBUTION
- * ● EXPERIMENT SUPPORT
- SYSTEM TEST HARDWARE
  - FUNCTIONAL MODEL
  - PROTOTYPE MODEL
- * ● EXPERIMENT ACCOMMODATION MODEL

ASSEMBLY LEVEL 6

* ● SYSTEM INTEGRATION

- PERFORMANCE
  MANAGEMENT
- CONFIGURATION
  MANAGEMENT
- DATA
  MANAGEMENT
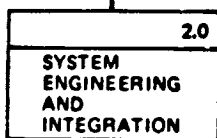
- CPL/SPACELAB
  INTEGRATION
- CLOUD PHYSICS
- EXPERIMENT SU
- GSE
- SAFETY RELIAB
  QUALITY ASSUR

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┌───────────────────────────────────┐
│ *INCLUDES ITEMS TO BE ACCOMPLISHED │
│  BY SPACELAB IN SUPPORT OF THE     │
│  CLOUD PHYSICS EXPERIMENT LABORATORY│
│  PROJECT                           │
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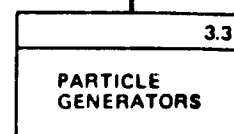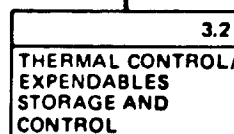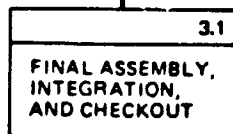
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                    │                 2.0  │
                    │ SYSTEM               │                          ┌──────────
                    │ ENGINEERING          │                          │
                    │ AND                  │                          │  CLO
                    │ INTEGRATION          │                          │  EXP
                    └──────────────────────┘                          │  LAB
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- CPL/SPACELAB INTEGRATION
- CLOUD PHYSICS LAB
- EXPERIMENT SUPPORT
- GSE
- SAFETY RELIABILITY AND QUALITY ASSURANCE

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┌──────────────────────┐  ┌──────────────────────┐  ┌──────────────────────┐
│                 3.1  │  │                 3.2  │  │                 3.3  │
│ FINAL ASSEMBLY,      │  │ THERMAL CONTROL/     │  │ PARTICLE             │    DA
│ INTEGRATION,         │  │ EXPENDABLES          │  │ GENERATORS           │    MA
│ AND CHECKOUT         │  │ STORAGE AND          │  │                      │
│                      │  │ CONTROL              │  │                      │
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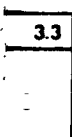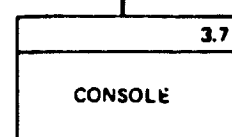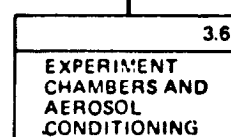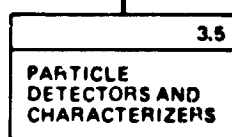
3.2.1 INTEGRATION, ASSEMBLY AND CHECKOUT	3.3.1 INTEGRATION, ASSEMBLY, AND CHECKOUT
3.2.2 THERMAL CONTROL	3.3.2 WIRE PROBE RETRACTOR GENERATOR
3.2.3 FLOW HUMIDITY AND PRESSURE CONTROL	3.3.3 WATER DROP IMPELLER GENERATOR
3.2.4 EXPENDABLES STORAGE	3.3.4 VIBRATING ORIFICE GENERATOR
3.2.5 INSTRUMENTATION AND DISPLAY SUBASSEMBLY	3.3.5 EVAPORATOR/ CONDENSER GENERATOR
3.2.6 EXPENDABLES	3.3.6 SPRAY ATOMIZER GENERATOR
3.2.7 CLEANSING PURGE AND VENT SUBASSEMBLY	3.3.7 POWDER DISPERSION GENERATOR
	3.3.8 PARTICLE INJECTOR AND SIZE CONDITION
	3.3.9 INSTRUMENTATION/ DISPLAYS
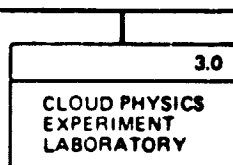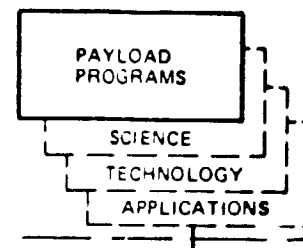
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3 4.8 C

PAYLOAD
PROGRAMS

SCIENCE

TECHNOLOGY

APPLICATIONS

3.0

CLOUD PHYSICS
EXPERIMENT
LABORATORY

| **3.3** | **3.4** DATA MANAGEMENT | **3.5** PARTICLE DETECTORS AND CHARACTERIZERS | **3.6** EXPERIMENT CHAMBERS AND AEROSOL CONDITIONING | **3.7** CONSOLE | |

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3.4.1 INTEGRATION, ASSEMBLY, AND CHECKOUT
3.4.2 CONTROL PROCESSOR ASSEMBLY
3.4.3 TAPE RECORDER ASSEMBLY*
3.4.4 MASTER CONTROL ASSEMBLY
3.4.5 SIGNAL CONDITION ELECTRIC ASSEMBLY
3.4.6 INSTRUMENTATION AND DISPLAY ASSEMBLY
3.4.7 EXPENDABLES
3.4.8 CABLE ASSEMBLIES

*FURNISHED BY SPACELAB OR GFE

3.5.1 INTEGRATION, ASSEMBLY, AND CHECKOUT
3.5.2 OPTICAL PARTICLE COUNTER
3.5.3 PULSE HEIGHT ANALYZER
3.5.4 CONDENSATION NUCLEI COUNTER
3.5.5 MICROPOROUS FILTER
3.5.6 QUARTZ CRYSTAL MASS MONITOR
3.5.7 CASCADE · IMPACTOR
3.5.8 ELECTRIC AEROSOL SIZE ANALYZER
3.5.9 SCATTEROMETER
3.5.10 LIQUID WATER CONTENT METER
3.5.11 DROPLET SIZE DISTRIBUTION METER
3.5.12 OPTICAL THERMOELECTRIC DEW POINT HYGROMETER
3.5.13 ELECTRIC DEW POINT HYGROMETER
3.5.14 INSTRUMENTATION/ DISPLAY

3.6.1 INTEGRATION, ASSEMBLY, AND CHECKOUT
3.6.2 STATIC DIFFUSION LIQUID
3.6.3 STATIC DIFFUSION ICE CHAMBER ASSEMBLY
3.6.4 GENERAL CHAMBER ASSEMBLY
3.6.5 EXPANSION CHAMBER ASSEMBLY
3.6.6 CONTINUOUS FLOW DIFFUSION CHAMBER ASSEMBLY
3.6.7 EARTH SIMULATION CHAMBER ASSEMBLY
3.6.8 NUCLEI CONDITIONING ASSEMBLY

3.7.1 INTEGRATION, ASSEMBLY, AND CHECKOUT
3.7.2 CONSOLE SUPPORT STRUCTURE AND SUBASSEMBLY
3.7.3 POWER CONTROL AND DISTRIBUTION
3.7.4 CONSOLE PANELS AND DRAWER SUBASSEMBLY
3.7.5 OVERHEAD STORAGE SUBASSEMBLY
3.7.6 FLOOR SEGMENT SUBASSEMBLY
3.7.7 INSTRUMENTATION/ DISPLAYS

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APPLICATIONS

CLOUD PHYSICS
EXPERIMENT
LABORATORY
PROJECT

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PRODUCTION

OPERATIONS

4.0	5.0	6.0	7.0
EXPERIMENT SUPPORT HARDWARE	SYSTEM TEST	GROUND SUPPORT EQUIPMENT	FACILITIES

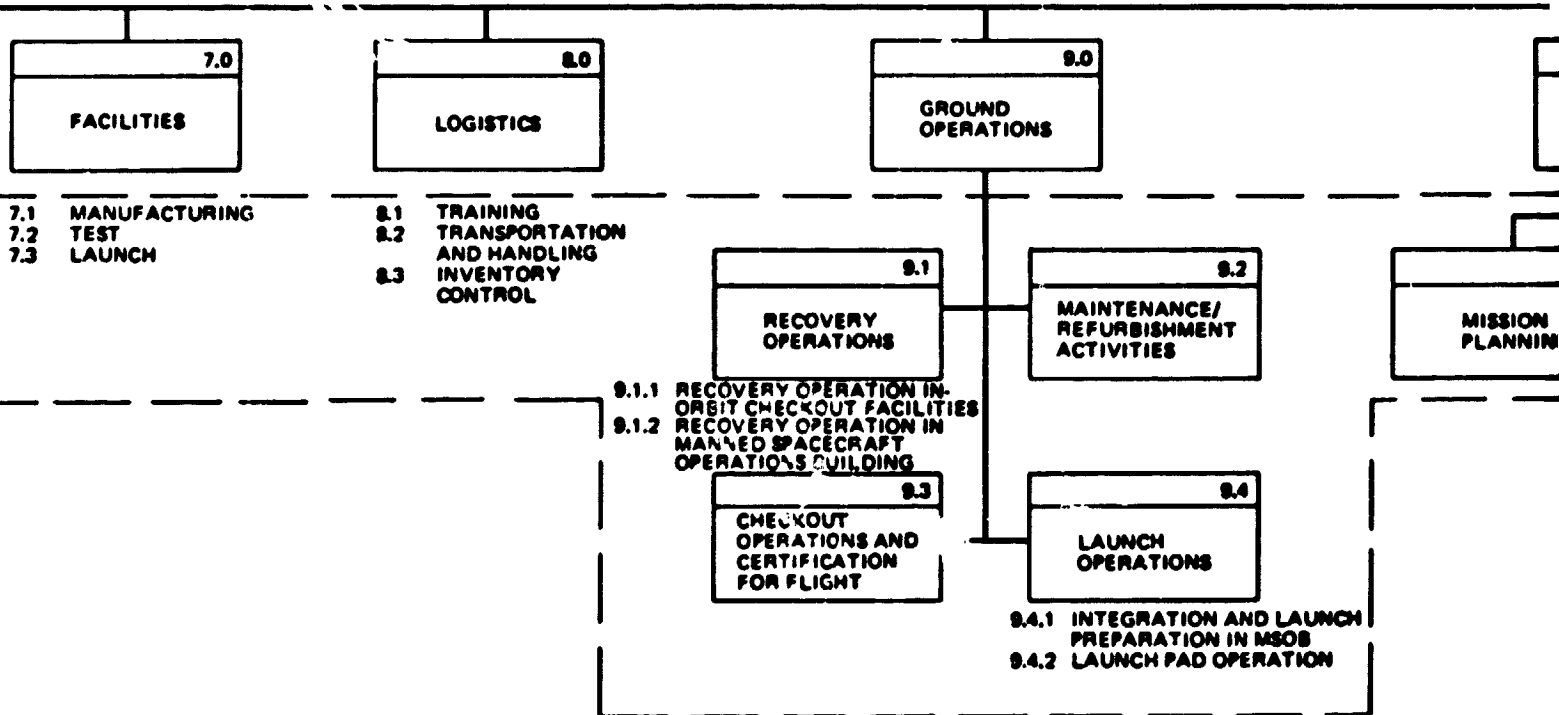|	
3.7	3.8
ONSOLE	OPTICAL AND IMAGING DEVICES

5.1 SYSTEM TEST
PLANNING
5.2 MAJOR TEST
ARTICLES
5.2.1 MOCKUPS
5.2.2 FUNCTIONAL
MODEL
5.2.3 PROJECT
VERIFICATION
MODEL
5.3 SYSTEM
DEVELOPMENT
TESTING
5.4 SYSTEM
VERIFICATION
TESTING

6.1 GSE INTEGRATION
6.2 ELECTRICAL GSE
6.3 MECHANICAL GSE
6.4 TRANSPORTATION
AND HANDLING GSE
6.5 SOFTWARE GSE

7.1 MANUFACTURING
7.2 TEST
7.3 LAUNCH

NTEGRATION,
ASSEMBLY,
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NSOLE
UPPORT
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ANELS AND
RAWER
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ERHEAD
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UBASSEMBLY
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UBASSEMBLY
ISTRUMENTATION/
LAYS

3.8.1 INTEGRATION,
ASSEMBLY,
AND CHECKOUT
3.8.2 CINE CAMERA
(35 MM)
3.8.3 STILL CAMERA
(35 MM)
3.8.4 MICROSCOPE,
TRINOCULAR
3.8.5 VIDEO CAMERA
ASSEMBLY (16 MM)
3.8.6 LIGHT SOURCE
3.8.7 ANEMOMETER
3.8.8 STEREO
MICROSCOPE
3.8.9 IR MICROSCOPE
3.8.10 SUPPORT EQUIP/
EXPENDABLES
3.8.11 DISPLAYS

7.0
FACILITIES

8.0
LOGISTICS

9.0
GROUND OPERATIONS

7.1 MANUFACTURING
7.2 TEST
7.3 LAUNCH

8.1 TRAINING
8.2 TRANSPORTATION AND HANDLING
8.3 INVENTORY CONTROL

9.1
RECOVERY OPERATIONS

9.2
MAINTENANCE/ REFURBISHMENT ACTIVITIES

MISSION PLANNIN

9.1.1 RECOVERY OPERATION IN-ORBIT CHECKOUT FACILITIES
9.1.2 RECOVERY OPERATION IN MANNED SPACECRAFT OPERATIONS BUILDING

9.3
CHECKOUT OPERATIONS AND CERTIFICATION FOR FLIGHT

9.4
LAUNCH OPERATIONS

9.4.1 INTEGRATION AND LAUNCH PREPARATION IN MSOB
9.4.2 LAUNCH PAD OPERATION

	10.0 FLIGHT OPERATIONS		11.0 PRINCIPAL INVESTIGATOR OPERATIONS

10.1 MISSION PLANNING	10.2 FLIGHT CONTROL AND EVALUATION	11.1 PI PLANNING OPERATIONS	11.2 PI PREFLIGHT OPERATIONS	11.3 PI FLIGHT/ POSTFLIGHT OPERATIONS

11.1.1 PRELIMINARY EXPERIMENT PLAN (UNFUNDED)

11.1.2 EXPERIMENT PLAN DEFINITION

11.2.1 FLIGHT PLAN ACTIVITIES

11.2.2 FLIGHT CREW TRAINING AND BASELINE DATA SUPPORT

11.3.1 MISSION SUPPORT ACTIVITIES

11.3.2 FINAL REPORT PREPARATION

NOTE: THIS PROPOSED WBS IS ONLY TO BE USED TO ESTABLISH A TOTAL CLOUD PHYSICS EXPERIMENT LABORATORY PROJECT LIFE CYCLE COST. FINAL REVISION — 5 SEPTEMBER 1974